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(54) Writing optical disk data.

(57) A write control method for writing optical disk data wherein pits are written on a medium by a write signal composed of mark signal parts and space signal parts, the length of each pit representing the optical disk data, having the steps of:
converting the mark signal parts to pulses and generating a series of pulse trains which correspond to the lengths of the mark signal parts, respectively;
controlling length and/or amplitude of or in each of the pulse trains in accordance with the length of the space signal part immediately before the mark signal part concerned; and
applying successively the controlled pulse trains to laser irradiation means so that the pits are written.

Apparatus for controlling writing is also provided.

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Writing optical disk data.

The present invention relates to the writing of optical disk data, in general to control of writing of optical disk data, and to control of writing of optical disk data by means of a laser beam.

In recent years, as mass storage computer systems have been developed, optical disks such as magneto-optical disks, phase-change optical disks and the like are becoming increasingly important as an erasable mass storage media. For this reason, an optical disk apparatus has been developed which records mass document data or image data on to a medium in the form of an optical disk.

Data recording in an optical disk medium is performed by inverting the magnetisation of the disk medium or changing the crystalline state of the disk medium, with the aid of a thermal effect brought about by the irradiation of a laser beam on to the disk medium. With the recording methods used, particularly a so-called mark-length recording method in which the lengths of a written signal (for example, corresponding to laser irradiation) and an unwritten signal (for example, corresponding to laser non-irradiation) represent data, it is very important that an accurate signal shape be written on to a medium in order to reduce reading errors and enhance reliability of the apparatus.

It should here be noted that the signal recorded on a disk medium is generally called a "bit, mark, or pit". In a rewritable optical disk medium such as a magneto-optical disk, although a signal written by laser irradiation does not actually make or involve a dent or pit in the disk medium, the written signal will hereinafter be referred to as a "pit", in accordance with the custom in this field of optical technology. In addition, an electric signal which corresponds to the length of the pit will hereinafter be referred to as a "mark".

The description below, in particular in relation to the present invention, will refer specifically to optical disks of the mark-length recording type. Although magneto-optical disks presently in use are generally of the bit-position recording type and not of mark-length recording type, it is expected that magneto-optical disks will shift to the mark-length recording type, because double bit density is provided.

As magneto-optical recording media, rare earth-transition metals such as TbFeCo may be used. In addition, in a magneto-optical disk, a magneto-optical recording film of TbFeCo, for example, is protected by upper and/or lower protecting films of, for example, SiO_2, SiN ... or rare-earth metal + transparent dielectric material such, for example, as Tb + SiO_2, Tb + ZnS, Tb + MgF_2, Tb + SiN, and Tb + TiC in order to prevent or inhibit oxidation of the magneto-optical recording medium.

Fig. 30 is provided for assistance in explaining a compact disk signal (hereinafter referred to as a "CD signal") as an example of mark-length recording. In this example, High ("H") and Low ("L") signals have lengths of 3τ to 11τ (τ represents a unit cycle = 230 ns), and these lengths represent data.

In a conventional optical disk apparatus, writing is performed by a method wherein a laser beam is irradiated only for a period of 5τ (230 ns x 5 = 1150 ns) for or in correspondence to a High signal and is not irradiated for or in correspondence to a Low signal.

In such a case, since the medium (on the disk) is rotating at a constant speed, the pulse width $n\tau$ of the write data is converted to nl (l: a unit length on a medium corresponding to a time τ) which is a pit length on the medium, and recorded. Written pits are shown in Figs. 31(a) and 31(b).

However, with the above-described conventional method and apparatus for writing optical disk data, if the speed of rotation of the medium is reduced, in order to provide for higher density data recording, a pit shape as shown in Fig. 31(c) will be written for a longer pit such as $n \geq 7$, due to the effects of heat generated when the pit is written. Consequently, the carrier-to-noise ratio (CNR), when reading data, is subject to deterioration, and there is a problem in that reading errors arise.

In order to overcome this problem, it has been proposed to intermittently apply a laser beam corresponding to a High signal. This method has been described, for example, in Japanese patent "KOKAI", Publication Nos. 63-160017, 63-263632, 62-229542, 63-266632, 63-153726 and 63-266633.

However, with such intermittent laser beam application, deterioration of the CNR when speed of rotation of the medium is decreased cannot be mitigated beyond a certain degree.

The inventors have appreciated that, if the rotating speed of the medium is decreased, then the influence of heat remaining from a previous pit writing, as well as heat generated during a present pit writing, becomes large. Therefore, the write starting position of a pit varies depending upon the length of the space between pits (length of the space following the previously written pit). Consequently, there is a variation in the length of the written pit.

Although the above-mentioned method can in a sense overcome the problem associated with heat generated during pit writing, it cannot overcome the

problem associated with remaining heat from previous pit writing.

A need exists for a means of preventing CNR deterioration when high density data writing is employed.

A technique which can be related to the problem associated with remaining heat from previous pit writing has been proposed and is described, for example, in Japanese patent "KOKAI", Publication Nos. 63-269321, 63-302424 AND 64-59633.

However, the technique described in the above publications does not address or solve the problem addressed by the present invention, as will be described below.

The techniques of the above-described publications will hereinafter be described in detail.

1. Japanese patent "KOKAI" Publication No. 63-160017

The apparatus of this publication is constructed such that means for controlling laser light divides laser light into a plurality of pulses and applies the pulses within a time corresponding to the length of a signal pit. The laser light controlling means divides the laser light in accordance with the length of the signal pit, makes the width of each leading pulse of the divided laser pulses wider than the widths of the succeeding pulses, and further makes the intensity of each leading pulse of the divided laser pulses larger than the intensities of the succeeding pulses.

Thus, this publication describes writing performed by the laser light in the form of pulses, but it does not disclose a concrete pulse-forming means.

2. Japanese patent "KOKAI" Publication No. 63-263632

The apparatus of this publication is constructed such that means for controlling laser light divides laser light into two pulses immediately before the laser irradiation duration is completed, and applies the two pulses within a time corresponding to the length of a signal pit. The apparatus may be structurally simpler than that of the above publication No. 63-160017.

3. Japanese patent "KOKAI" Publication No. 62-229542

The apparatus of this publication includes a pulse generator for generating at constant cyclic rate pulses which have a predetermined constant pulse width corresponding to the light beam irradiation time that is suited to the recording sensitivity of a recording layer, and includes a gate circuit for controlling transmission of the pulse signal from the pulse generator to a laser drive circuit, according to a record pulse output from a record pulse generator. The laser drive circuit controls the light output of a laser light source by means of the output of the gate circuit. The apparatus relates to means for converting CD signals to pulse signals. Pulse width is constant and cannot be varied within a record pulse.

4. Japanese patent "KOKAI" Publication No. 63-266632

In a recording method for recording data by means of a change in the atomic arrangement of a recording medium that is caused by irradiating an energy beam such as a light, electron beam and the like, a record point is formed with one or more pulses having a pulse width that is shorter than the length of time the centre of the energy spot passes from one end of the record point to the other. The publication describes that the writing is performed by the laser beam in the form of pulses, and the pulse width is preferably shorter than 3/4 of a pit length, more preferable shorter than 1/2, and most preferable shorter than 1/4 of a pit length. No description is made in relation to pulse-forming means.

5. Japanese patent "KOKAI" Publication No. 63-153726

It is described that the amount of energy in each radiation pulse of a series of radiation pulses is determined by the pulse position within the pulses, with consideration given to the condition that the sum of the temperature rise in a data body caused by one radiation pulse and the temperature that has already been generated by the previous radiation pulses of the series of radiation pulses is always constant. This is a patent application that has been filed by the co-authors of a paper cited below in the specification of the present application, and is in substance identical with the paper.

6. Japanese patent "KOKAI" Publication No. 63-266633

This publication discloses that a write signal pulse is divided into three parts: a start part, an intermediate part and an end part. Further description of the disclosure of this publication is given

below.

7. Japanese patent "KOKAI" Publication No. 63-269321

The apparatus disclosed in this publication is characterised in that its laser light control mechanism shortens a laser light irradiation time, when a longer pit is written, or shortens the laser light irradiation time, when a blank space length forms a shorter pit. In this case the mechanism of pit formation is based on ablation of films, and therefore is applied to write-once type disks for archival purposes. No description is given in relation to concrete means to shorten the laser light irradiation time, when a blank length forms a shorter pit. Further, the method disclosed in this publication is a normal writing method, and no description is given in relation to pulse-forming means.

8. Japanese patent "KOKAI" Publication No. 63-302424

The apparatus disclosed in this publication is characterised in that the laser light control means shortens a laser light irradiation time, when a blank length forms a shorter pit, and advances the irradiation time, when a blank length forms a longer pit. This technique is almost the same as that of the above publication No. 63-269321. No description is given in relation to pulse-forming means.

9. Japanese patent "KOKAI" Publication No. 64-59633

In optical disk apparatus for pit position recording, in order to avoid the phenomenon that, when a write space is short, the diameter of the succeeding pit will become large, the write space is detected, and if the space is short, the write laser power is then reduced. It is disclosed that the pulse space is detected and the amount of the laser light is varied according to the detected pulse space. This publication relates to pit position recording.

Thus, in a general sense, the prior art disclosures relate to the use of pulse techniques and to the control of laser irradiation time or power.

An embodiment of the present invention can provide an improved write control method and apparatus for writing optical disk data, capable of maintaining accurate pit shape even when high density data recording is performed, in order to obtain regenerative signals of better CNR (carrier-to-noise ratio)

In accordance with an embodiment of the present invention, the influence of remaining heat from previous pit writing as well as the heat generated during (present) pit writing is effectively corrected.

In accordance with a write control method embodying the present invention for writing optical disk data wherein pits are written by a write signal composed of mark signal parts and space signal parts, and the length of each pit represents the optical disk data, the following steps are provided: converting the mark signal parts to pulses and generating a series of pulse trains which correspond to lengths of the mark signal parts, respectively: controlling lengths and/or amplitudes of or in each of the pulse trains in accordance with a length of the space signal part immediately before the mark signal part; and applying successively the controlled pulse trains to laser irradiation means so that the pits are written.

In a write control method embodying the present invention for writing optical disk data wherein pits are written on a medium by a write signal composed of mark signal parts and space signal parts, and the length of each pit represents the optical disk data, the write control method may comprise the step of dividing each of the mark signal parts into three parts: (a) a start part which elevates a temperature of the medium rapidly to a writable temperature, (b) an intermediate part which maintains a balance between the elevated temperature of the medium and heat radiation from the medium, and (c) an end part which maintains a temperature fall resulting from the completion of a laser beam irradiation at a predetermined condition. The three parts of each mark signal part are converted to pulses so that pulse width of each of the three parts accords with favourable conditions. Then, a series of pulse trains which correspond to lengths of the mark signal parts is generated. If the length of the mark signal part is varied, the number of pulses of the intermediate part of the mark signal part is varied. The write control method further comprises the steps of controlling length and/or amplitude of each of the pulse trains in accordance with length of the space signal part immediately before the mark signal part, and applying successively the controlled pulse trains to laser irradiation means so that the pits are written on the medium.

In a write control method embodying the present invention for writing optical disk data wherein pits are written by a write signal composed of mark signal parts and space signal parts, and length of each pit represents optical disk data, the write control method may comprise the step of converting the mark signal parts to pulses and generating a series of pulse trains which corre-

spond to lengths of the mark signal parts, respectively. The write control method further comprises the step of time condensing a part or the whole of each pulse train in accordance with length of a space signal part immediately before the mark signal part in such a manner that a position of an end pulse of the each pulse train becomes the same position. The write control method further comprises the step of applying successively the time condensed pulse trains to laser irradiation means so that the pits are written.

In addition, in a write control apparatus embodying the present invention for writing optical disk data wherein pits are written on an optical disk medium by laser irradiation means in accordance with a write signal composed of mark signal parts and space signal parts, and length of each pit represents optical disk data, the write control apparatus comprises first delay means for delaying with a first predetermined range each of the mark signal parts, and second delay means for further delaying each of the mark signal parts delayed by the first delay means with a second predetermined range. The write control apparatus further comprises control signal generating means for generating a start part control signal, an intermediate part control signal and an end part control signal from outputs of the first and second delay means. The write control apparatus further comprises pulse-forming means for dividing each of the mark signal parts into three parts, a start part which elevates a temperature of the medium rapidly to a writable temperature, an intermediate part which maintains a balance between the elevated temperature of the medium and heat radiation from the medium, and an end part which maintains a temperature fall resulting from the completion of a laser beam irradiation at a predetermined condition, and for converting the three parts of each mark signal part and generating a series of pulse trains which correspond to lengths of the mark signal parts, respectively. The write control apparatus further comprises pulse train control means for controlling length and/or amplitude of each of the pulse trains in accordance with a length of the space signal part immediately before the mark signal part.

In a write control apparatus embodying the present invention for writing optical disk data wherein pits are written on an optical disk medium by laser irradiation means in accordance with a write signal composed of mark signal parts and space signal parts, and length of each pit represents optical disk data, the write control apparatus may comprise pulse-forming means for converting the mark signal parts to pulses and generating a series of pulse trains which correspond to lengths of the mark signal parts, respectively; space recognition means for recognising a length of the space signal part immediately before the mark signal part; and time condensation means for time condensing a part or whole of each pulse train in accordance with the recognition result obtained from the space recognition means in such a manner that a position of an end pulse of the pulse train becomes the same position.

Reference is made, by way of example to the accompanying drawings, in which:-

Figs. 1(a) to 1(c) are diagrams illustrating a favourable write pulse condition and pit shape, for assistance in explaining features of embodiments of the present invention;

Fig. 2 shows schematically the structure of a write control apparatus for writing optical disk data in accordance with a first embodiment of the present invention;

Fig. 3 shows schematically the structure of a pulse-forming circuit of Fig. 2;

Fig. 4 is a timing diagram illustrating features of operation of the first embodiment;

Fig. 5 shows schematically the structure of a reference signal generating circuit of the first embodiment;

Fig. 6 is a timing diagram relating to the reference signal generating circuit;

Fig. 7 is a timing diagram relating to a pulse train control circuit of the first embodiment;

Fig. 8 is a timing diagram relating to a second embodiment of the present invention;

Fig. 9 shows schematically an output system of a pulse-forming circuit of a third embodiment of the present invention;

Fig. 10 shows schematically the structure of pulse prohibition means of the third embodiment;

Figs. 11(a) to 11(d) are timing diagrams relating to the third embodiment;

Fig. 12 shows schematically the output system of a pulse-forming circuit of a fourth embodiment of the present invention;

Figs. 13(a) and 13(b) are timing diagrams relating to control of light output of the fourth embodiment;

Fig. 14 is a diagram illustrating results obtained by correcting the influence of remaining heat in accordance with the first and second embodiments:

Fig. 15 is a block diagram schematically showing the structure of a pulse train control circuit of a fifth embodiment of the present invention;

Fig. 16 is a timing diagram relating to the fifth embodiment;

Fig. 17 shows a pulse output that has been formed by a plurality of passing-path selection means of the fifth embodiment;

Fig. 18 shows schematically the structure of a circuit for generating a leading pulse in accordance with a sixth embodiment of the present

invention;

Fig. 19 shows the structure of a circuit for selecting a radius position in accordance with the sixth embodiment;

Fig. 20 is a diagram showing an example of correction in relation to remaining heat in accordance with a seventh embodiment of the present invention;

Fig. 21 schematically illustrates the structure of a pulse train control circuit of the seventh embodiment;

Fig. 22 is a diagram showing a characteristic of a voltage controlled delay circuit of the seventh embodiment;

Fig. 23 is a diagram showing a serrate control voltage and delay time of the seventh embodiment;

Fig. 24 is a diagram showing a characteristic of the voltage controlled delay circuit of the seventh embodiment;

Figs. 25(a) to 25(c) are diagrams showing an output pulse train in which correction of remaining heat by time condensation in accordance with the seventh embodiment has been performed;

Fig. 26 schematically illustrates the structure of a delay-time control circuit of the seventh embodiment;

Figs. 27(a) to 27(e) are diagrams illustrating the operational waveform of each part of the delay-time control circuit of the seventh embodiment;

Fig. 28 schematically illustrates the structure of a delay-time control circuit of an eighth embodiment of the present invention;

Figs. 29(a) and 29(b) are diagrams illustrating the operational waveform of each part of the delay-time control circuit of the eighth embodiment;

Fig. 30 illustrates an example of a compact disk signal;

Figs. 31(a) to (c) illustrate pits written by a conventional method; and

Fig. 32 is a diagram illustrating how the length of a written pit depends upon the length of a space immediately before the written pit.

The inventors have carried out investigations for analysing the problems mentioned above and addressed by the present invention.

The first problem, that the shape of pits cannot be written accurately if the rotational speed of the medium is reduced in order to perform high density data recording, can, in the view of the inventors, be explained as follows. If the rotation speed of the medium is a normal rotational speed, local temperature rise of the medium caused by laser beam irradiation and temperature fall of the medium due to heat radiation are maintained at a fixed balance, and a boundary where (within which) writing as a result of thermal effects is provided (hereinafter referred to as a "write boundary") is almost consistent with the diameter of the laser beam. Therefore, if a pit of 11τ is written by the laser beam, a pit 11 l in length and d (d: diameter of laser beam) in width will be formed on the medium.

If, on the other hand, the rotational speed of the medium is made slower, for providing high density data recording, then laser beam irradiation energy per unit area becomes large. Consequently, temperature fall as a result of heat radiation becomes insufficient, and as irradiation time becomes longer, heat gradually accumulates and flows into positions before and after the beam irradiation position. The energy of the laser beam necessary to perform a writing for a fixed time with the aid of the thermal effect has a lower limit. Therefore, for example, when the rotational speed is reduced to 1/2, writing cannot be performed with laser beam energy reduced to 1/2, and consequently the first problem described above arises at all times.

Therefore, if a longer pit such as 7τ or more is written, the accumulation of heat becomes larger as the laser beam is advanced to the 2 l′ position, the 3 l′ position and to the 4 l′ position of the pit length 7 l′ of Fig. 31(c). As a result, the influence of heat upon adjacent positions is gradually increased, and the aforesaid write boundary is also enlarged beyond the laser beam diameter d. Since in the vicinity of the pit end (in the above example, 7 l position) the laser beam irradiation is completed immediately after the pit end, and temperature fall due to heat radiation becomes dominant, the write boundary comes to correspond almost to the beam diameter.

Therefore, in the above example, a pit shape as shown in Fig. 31(c) will be formed. Particularly, in a phase-change type medium in which recording is effected by varying reflectivity by means of a change of crystalline state (crystalline phase), the crystalline state is changed by quenching or annealing from a molten state in order to write High and Low data. Therefore, in such a case, the influence of heat transferred from neighbouring positions becomes extremely large.

As an example, consider a medium of the phase change type which writes High data by quenching. If a written pit becomes longer (for example, 7τ or more) and therefore there exists an effect by which heat has an influence upon adjacent positions, then a 3τ position is subjected to the influence of the heat from a 4τ position, and the 4τ position is subjected to the influence of the heat from a 5τ position. Thus, a $n\tau$ position will be subjected to the influence of the heat from a $(n + 1)\tau$ position and consequently the cooling is performed not by quenching but by annealing. Therefore, High data writing of such a longer pit becomes extremely unstable. In order that a stable

High data writing state is obtained even in the case of the writing of longer pits, that is, in order that a stable rapid cooling state is achieved, it is effective that a laser beam is intermittently irradiated over the length of a pit $n\tau$ (n = 3 to 11). Writing by a pulse train having a width of 80 ns at a frequency of 4.3 MHz (τ = 230 ns) is described in the paper "Phase-change Optical Data Storage in GaSb", APPLIED OPTICS (Vol. 26, No. 22, 15th November 1987).

The inventors of this application have written a variety of High pit lengths (hereinafter referred to as "mark lengths") on a medium in accordance with the examples of the above-described paper "Phase-change Optical Data Storage in GaSb" and investigated the shape of the written pits. As a result, in writing effected by a pulse train having a fixed pulse width, pulse width conditions in which a favourable pit shape is obtained for mark lengths 3τ to 11τ could not be found even by varying the pulse width or light power. For the shortest mark length of 3τ, a favourable pit shape was obtained when the writing was performed with three pulses of 180 ns pulse width. However, if the longest mark length of 11τ is written with 11 pulses of such type, the same abnormality of the pit shape occurs as with writing by successive lights mentioned in the prior art, since light energy is extremely large.

On the other hand, with 120 ns pulse width, which provides a favourable pit shape in the case of a mark length of 11τ, a pit of 3τ length could not be written normally because of the insufficient light energy.

A recording method in which the pulse width of a pulse train representing the mark length is changed is described in the Japanese "KOKAI" publication, No. 63-266633 mentioned above. In this method, the pulse train is divided into three parts: a start part, an intermediate part and an end part, and the pulse widths of the start part and end part are wider than the pulse width of the intermediate part. However, in this method, with each of the start part, intermediate part and end part is constituted by a plurality of pulses, then the pulse widths of the pulses of each part cannot be set individually.

The inventors have determined that the above method is not suited to provide that an optimum written pit shape is obtained under different conditions, having regard to the problems described above and addressed by the present invention.

Referring to features of embodiments of the present invention which will be described below, it will be clear that the Japanese "KOKAI" publication, No. 63-266633, does not disclose means for setting pulse width of each part independently, nor does it disclose pulse prohibition means for prohibiting generation of each pulse independently. The method disclosed in the publication is not suitable to obtain an optimum written pit shape, and cannot completely resolve the above-mentioned problems. In addition, no disclosure is provided in relation to means for controlling the length of a write signal in accordance with a space length immediately before the write signal, such means being a major element of embodiments of the present invention.

The inventors have had the insight that an apparatus which is capable of setting independently each pulse width of a pulse train forming the mark described above, as will hereinafter be described, could solve the problems.

A variety of mark lengths were written under the combination of various pulse widths in order to observe the shape of the written pits.

Figs. 1(a) to 1(c) illustrate pits written with favourable write pulse conditions obtained from the above observations.

Fig. 1(a) illustrates a pit shape which has been written with a pulse cycle T = τ (230 ns), a first pulse width 200 ns and a second pulse width 150 ns (start part), a third pulse width 120 ns and fourth-sixth pulse widths 100 ns (intermediate part), and a seventh pulse width 130 ns (end part), by using an input signal having High data of 7τ (mark) and Low data of 7τ (space). The written pit shape has been much improved, as compared with that shown in Fig. 31(c) which was obtained with writing by a continuous laser beam.

Fig. 1(b) illustrates a pit shape written with a first pulse width 200 ns and a second pulse width 150 ns (start part), a third pulse width 120 ns and fourth-tenth pulse widths 100 ns (intermediate part), and an eleventh pulse width 130 ns (end part), by using an input signal having High data of 11τ (mark) and Low data of 7τ (space).

Likewise, Fig. 1(c) illustrates a pit shape which written with a first pulse width 200 ns and a second pulse width 150 ns (start part), and a third pulse width 130 ns (end part, in this case there is no pulse corresponding to an intermediate part), by using an input signal having High data of 3τ (mark) and Low data of 7τ (space). In both the cases, a favourable pit shape is obtained as in the case of Fig. 1(a).

The inventors have had the insight that the pulses consist of (1) a part (start part) which elevates the medium rapidly to a writable temperature, (2) a part (intermediate part) which maintains a balance between the elevated temperature in the start part and the heat radiation from the medium, and (3) a part (end part) which maintains the temperature fall resulting from the completion of the laser beam irradiation at favourable conditions. Therefore, they have perceived, increase or decrease in relation to the pulses of the intermediate part, to change the length of the intermediate part

in accordance with a change of the mark length, is merely to change the length of the part having a function of maintaining temperature. It follows from this that a favourable pit shape can be obtained independently of the mark length.

Note that, with respect to the intermediate part pulse, a more favourable pit shape is obtained if the pulse width of the leading pulse is wider than the pulse widths of the other pulses, as shown in Figs. 1(a) and 1(b).

In the experiments described above, only the mark length is noted as varying, and the space length has been assumed constant for convenience. However, in an actual CD signal, data is recorded by combinations of marks and spaces having lengths of 3τ to 11τ. Therefore, after a mark has been written, a space between the mark and the next mark may vary between 3τ and 11τ. Particularly, in a phase-change type medium which performs a recording by changing the crystalline state by means of quenching or annealing of the medium, the influence of the remaining heat from the previous pit becomes very important.

In order to analyse the influence of the remaining heat, changes of the mark length were measured with variation of space length from 3τ to 11τ. The test results are shown in Fig. 32.

The test medium was covered with a recording film of 60 nm having a composition of $(In_{0.40}Sb_{0.60})_{0.94}Ge_{0.06}$ and tested at a line speed of 1.2 m/s. Test results relating to written mark lengths 3τ, 7τ and 11τ are shown with the space length (in τ) immediately preceeding the written mark taken on the abscissa and with the written mark length in μs taken on the ordinate. In Fig. 32, "x" represents data obtained when a normal writing (laser power 5 mW) was performed without converting an input CD signal into pulses, and "o" represents data obtained when an input CD signal was converted into pulses at the favourable pulse conditions described above (laser power 12 mW).

With normal writing the difference between the written mark lengths reaches 300 ns (corresponding to 1.3τ) with respect to the space lengths 3τ and 11τ, and consequently it is impossible to determine the written mark length accurately.

With pulse writing the difference between the written mark lengths is 150 ns (corresponding to 0.65τ) with respect to the space lengths 3τ and 11τ, and thus writing is certainly improved. However, since this difference value is 65% of τ (= 230 ns) and exceeds 0.5τ which is a discriminant reference of each mark length during readout, mark lengths cannot be discriminated accurately.

Thus, because the influence of the remaining heat is extremely large, mere pulse formation based on the conventional methods described above cannot provide for accurate write and read of an actual mark-length record signal such as a CD signal.

Embodiments of the present invention to be described hereinafter are those which provide a write control method and apparatus for writing optical disk data which are capable of overcoming the problems described above, writing accurately mark-length record signals such as CD signals, and obtaining regenerative signals of better CNR and high quality.

First Embodiment

Referring now in greater detail to the drawings and initially to Figs. 2 to 7, there is illustrated a first embodiment of a write control method and apparatus for writing optical disk data according to the present invention. Fig. 2 is used to show the structure of the write control apparatus for writing optical disk data. In Fig. 2, the write control apparatus comprises a first delay circuit (first delay means) 1 to which an input CD signal D_0 (corresponding to a write signal of a record pit) is input and in which the input CD (compact disk) signal D_0 is delayed with a predetermined range, and a second delay circuit (second delay means) 2 in which a CD signal (first delay signal D_1) delayed in the first delay circuit 1 is further delayed with a predetermined range. The write control apparatus further comprises a control-signal generating circuit 3 which generates a start part control signal A, intermediate part control signal B and end part control signal C from the output signals of the first and second delay circuits 1 and 2 (first and second delay signals D_1 and D_2). The write control apparatus further comprises a pulse-forming circuit (pulse-forming means) 4 which divides the write signal of the record pit (i.e., input CD signal D_0) into a start part, intermediate part and end part in response to the control signals A, B and C and which generates pulses respectively corresponding to the three parts, and a pulse train control circuit (pulse train control means) 10 which detects a space length immediately before the input CD signal D_0 and controls the length of a pulse train according to the space length.

A pulse-forming output from the above-described pulse-forming circuit 4 is input to a laser diode 5, which generates a laser beam in response to the pulse-forming output. The laser beam is focused through a lens 6 and irradiated on an optical disk medium 8 rotating about its rotational axis 7 so that a mark-length recording will be performed. The laser diode 5 and lens 6 as a whole constitute laser irradiation means 9.

The first delay circuit 1 and second delay

circuit 2 are preferably constituted by digital means such as a shift register in which a delay synchronised to a clock is obtained, but they may also be constituted by analog means such as a delay line. In addition, while description will be given for an exemplary case of this embodiment in which a first delay time and a second delay time are τ and 2τ, respectively, it is to be noted that the delay times may also be, for example, 1.5τ or 0.25τ as long as they are below a minimum space length (3τ for a CD signal) determined by a signal standard.

Fig. 3 is used to explain the structure of pulse-forming circuit 4. Although only one pulse-forming circuit 4 is shown in Fig. 3, for convenience, each part of the start part, intermediate part and end part requires the circuit shown in Fig. 3.

In Fig. 3, the pulse-forming circuit 4 is constituted by a clear circuit 11, a counter 12, a delay circuit 13, a decode circuit 14, a pulse-width set circuit 15, and an OR gate 16 as an aggregate circuit. The clear circuit 11 includes a delay circuit 17, an inverter 18 and a NAND gate 19. The clear circuit 11 synchronises with the fall edges of the control signals A, B and C and outputs a clear signal to the counter 12. The counter 12 has a clear terminal to which the clear signal is input, a count enable terminal to which each signal of the control signals A, B and C is input, and a clock terminal to which a pulse-forming clock signal is input. Assume now that the control signal A is first input to the counter 12. The counter 12 starts counting if the control signal A becomes "H" and stops counting if the signal A becomes "L". At this time, a clear pulse having a pulse width which is determined by a delay time (for example, 50 ns) of the delay circuit 17 is input from the clear circuit 11 to the clear terminal of the counter 12, and resets the counter 12 to a "0" state.

More specifically, if the control signal A with a pulse width of 2 shown in Fig. 4 is input, the state of the counter 12 then becomes 0 --> 1 --> 2 --> 0. The 2^0 position (A, $\overline{A}$), 2^1 position (B, $\overline{B}$) and 2^2 position (C, $\overline{C}$) and 2^3 (D, $\overline{D}$) position that are the outputs of the counter 12 have been input to the decode circuit 14, which is constituted by, for example, AND gates 20a to 20n (in this embodiment, n = 15). The reason for n = 15 is that 15 pieces of "1" to "F" are used and "0" is not used.

In addition, the pulse-width set circuit 15 comprises monostable multivibrators 21a to 21n (in this embodiment, n = 15). Each of these monostable multivibrators is provided with pulse-width adjustment means 22 such as a variable resistor, as shown in the monostable multivibrator 21a. Therefore, it is possible to set independently each pulse width of first to nth pulses.

When the counter 12 is in the "0" state, A = B = C = D = 0 and $\overline{A}$ = $\overline{B}$ = $\overline{C}$ = $\overline{D}$ = 1, and there is no combination in which all of the inputs of the decode circuit 14 become "1". Consequently, no signals appear at the output side of the decode circuit 14, since the output sides still remain "0". When, on the other hand, the state of the counter 12 is "1", A = $\overline{B}$ = $\overline{C}$ = $\overline{D}$ = 1 and $\overline{A}$ = B = C = D = 0. Consequently, a pulse-forming clock that has been delayed (for example, 50 ns) appears only in the output side of the AND gate 20a having an input combination of A . $\overline{B}$. $\overline{C}$. $\overline{D}$, and triggers the monostable multivibrator 21a. Since, when the state of the counter 12 is "2", B = $\overline{A}$ = $\overline{C}$ = $\overline{D}$ = 1 and $\overline{B}$ = A = C = D = 0, a pulse-forming signal appears only in the AND gate 20b and triggers the monostable multivibrator 21b. In this way, if the state of the counter 12 becomes "3", "4", "5", ..., and "15", then the monostable multivibrators 21c, 21d, 21e, ..., and 21n are triggered. That is to say, the monostable multivibrators 21a to 21n generate a first pulse, second pulse, ..., and nth pulse (n = 15), respectively, which are to be generated by the start part control signal A. Note that, if, as shown in Fig. 4, the width of the start part control signal A is 2τ and not changed, only two AND gates and two monostable multivibrators will be required.

The outputs of the monostable multivibrators 21a to 21n are logically synthesized in the OR gate 16 that is an aggregate circuit, which gate 16 then outputs a start part pulse in which a first pulse, second pulse, ..., and nth pulse appear in succession on a time base.

An intermediate part pulse and end part pulse are also produced and output in the same way as the start part pulse mentioned above. Moreover, the start part pulse, intermediate part pulse and end part pulse are logically synthesized by an aggregate circuit (not shown) and become a pulse-forming output shown in the lowest end of Fig. 4. The pulse-forming output is then applied to the laser diode 5.

The control-signal generating circuit and pulse-train control circuit will hereinafter be described. The basic operation of the control-signal generating circuit is first explained in accordance with the timing diagram shown in Fig. 4.

The input CD signal D_0 passes through the first delay circuit 1 and becomes the first delay signal D_1, which signal D_1 passes through the second delay circuit 2 and becomes the second delay signal D_2. While it will be described that in this embodiment the first delay time is τ and the second delay time is 2τ, for convenience only, it is to be noted that the delay times may also be 1.5τ and 0.25τ for example, as long as they are below a minimum space length (3τ for a CD signal) defined by a signal standard.

In the control-signal generating circuit 3 to which the signals D_0, D_1 and D_2 have been input, a logical operation is performed and consequently control signals $A = D_1.(\overline{D_1.\overline{D}_2})$, $B = (D_0\,D_1).(D_1.D_2)$ and $C = (D_1.D_2).\overline{B}$ are formed. Note that "." represents "AND (logical product" and "¯" represents "NOT (negation)". The control signals A, B and C become a start part control signal, intermediate part control signal and end part control signal, respectively. The timings of the control signals A, B and C with respect to the input CD signal D_0 are shown in Fig. 4. The pulse width of the start part control signal A is consistent with the second delay time (in the embodiment of Fig. 4, 2τ) of the second delay circuit 2, and the pulse width of the end part control signal C is consistent with the first delay time (in the embodiment of Fig. 4, τ) of the first delay circuit 1. In addition, the pulse width of the intermediate part control signal B is consistent with a value which is obtained by subtracting the first and second delay times of the first and second delay circuits 1 and 2 from the pulse width of the input CD signal. These consistencies are naturally obtained from the above logical operation which is performed to form the control signals A, B and C. Therefore, the pulse width of the start part control signal A and/or pulse width of the end part control signal C can be varied by varying the second delay time of the second delay circuit 2 and/or first delay time of the first delay circuit 1.

As shown in Fig. 2, the control signals A, B and C are inputted to the pulse forming circuit 4, and converted into a pulse forming output which has pulses corresponding in width and number to the control signals A, B and C. On the basis of the pulse forming output, the diode 5 mentioned above is driven so that the mark-length recoding will be performed on the optical disk medium 8.

Next, the operation of the pulse-train control circuit will be described in accordance with Figs. 5-7. In the pulse-train control circuit 10, a reference signal is generated which reduces the mark length (ultimately, the length of the pulse train) if the space length is shorter than the length of the space signal. As shown in Fig. 5, a monostable multivibrator 43, delay circuits 44, 45, inverters 46, 47, AND gate 48 and NAND gate 49 constitute the pulse-train control circuit 10 or 42, which circuit 42 resets at the fall of the input CD signal D_0 and sets at the fall of the first delay signal D_1 delayed by τ than the D_0 signal, as shown in Fig. 6. The above reference signal E is generated from the pulse-train control circuit 42. In addition, the monostable multivibrator 43 is provided with pulse-width adjusting means such as a variable resistor 50. The adjusting means adjusts the length of the reference signal to 7τ.

Fig. 7 is used to explain a timing that is set by an input CD signal having a mark 3τ, space 3τ, mark 3τ, space 7τ and mark 5τ. Although the reference signal E has a pulse width of 7τ, it becomes "L" if the reset signal (in Fig. 7, 5τ) appears before the pulse width of 7τ, and is again set to "H" by the set signal after τ. The reference signal E becomes "L" after 7τ. Since the timing at which the reference signal E is set is consistent with the fall of the first delay signal D_1, it can be judged that if the reference signal E is "H" at the rise of mark 3τ of the signal D_1, the space length of the signal D_1 immediately before the mark is below 7τ, and that if the reference signal E is "L" at the rise of mark 3τ of the signal D_1, the space length is above 7τ. If the space length is below 7τ, then the mark length is made shorter, and a start part auxiliary signal D is used in order to control the pulse train. The signal D is produced by an operation of $D = D_1 \cdot (\overline{D_1 \cdot D_3})$, using a third delay signal D_3 which delays the first delay signal D_1 by a length (in Fig. 7, τ) which the mark length of the first delay signal D_1 is shortened. Next, a mark length control signal $D \cdot E = F$ is produced from the reference signal E, and then a start part control signal $A \cdot \overline{F} = A'$ is produced. As shown in Fig. 7, when the space length is shorter than the reference signal E, the rise position of the control signal A' is delayed from that of the control signal A by τ. When, on the other hand, the space length is longer than the reference signal E, the rise position of the control signal A' is the same as that of the control signal A. Since the fall position of the control signal A' is the same as that of the control signal A, the write mark length can be controlled according to the length of the space. Instead of the control signals A, B and C described in the basic operation of the control-signal generating circuit 3, by inputting the control signals A', E and C to the pulse forming circuit 4, a pulse forming output (shown in the lowest end of Fig. 7) is obtained which has a pulse train having a length corresponding to the space length immediately before the mark length.

From the foregoing description, in this embodiment, the write signal for writing the pit is divided into three parts, which are then converted to pulses. Since the widths of the pulses can set independently, the laser beam can be irradiated on the medium at conditions optimum for the three parts described above. In addition, since the space length immediately before the write signal can be detected and since the length of the output pulse train can be controlled according to the detected space length, the influence of the remaining heat from the previous written pit can be effectively corrected. Therefore, even in the case of high density writing, the pit is accurately written, and

consequently a regenerative signal of better CNR can be obtained.

Although in the above description the counter of the pulse forming circuit 12 is binary and has four bit positions, the present invention is not limited to this. Of course, the number of positions can be increased, and a large number of pulse-width set circuits can be provided. In addition, instead of the monostable multivibrators for generating first to nth pulses, the pulse width may also be determined by digital means such as a counter.

Moreover, although analog means such as a monostable multivibrator has been used in the generation of the reference signal of the pulse-train control signal, digital means such as a counter may also be employed. In addition, although in the above description only one reference signal has been used, a plurality of reference signals may also be used. In that case a finer control can be achieved by combination with a plurality of start part auxiliary signals D. For example, a mark length is $-\tau$ for space lengths 3τ to 4τ, mark length is -0.5τ for space lengths 5τ to 7τ, and mark length is unchanged for space lengths 8τ to 11τ.

Second Embodiment

Fig. 8 is used to explain a second embodiment of the present invention. This embodiment is characterized in that the cycle of the pulse forming clock is $(1/2)\cdot\tau$. That is to say, since, as shown in Fig. 8, in this embodiment the resolution of the pulse formation is double the first embodiment, a finer pulse-width setting can be performed. Note that a pulse width condition of the pulses of the start part can be set as in the first embodiment, by setting the pulse widths of monostable multivibrators 21a and 21c to those of the monostable multivibrators 21a and 21c of the first embodiment and by setting the pulse trailing ends of monostable multivibrators 21b and 21d so that they will not exceed the pulse trailing end which was set in the monostable multivibrator 21a or 21c of the first embodiment.

Since in the pulse forming circuit 4 shown in Fig. 3 the outputs of the monostable multivibrators 21a to 21n are logically synthesized by the OR gate 16 which is an aggregate circuit, no failure occurs even if two pulses are generated at the same time. It is also possible that the monostable multivibrators 21a and 21c are set to $(1/2)\cdot\tau$ and the remaining pulse widths are set by the monostable multivibrators 21b and 21d. This can be applied to the end part in the same way. In addition, the cycle of the pulse forming clock can be set to $(1/3)\cdot\tau$ or $(1/4)\cdot\tau$ in order to increase the resolution.

Third Embodiment

Figs. 9-11 illustrate a third embodiment of the present invention. As shown in Fig. 9, this embodiment is characterized in that a pulse forming circuit 31 outputs a plurality of pulse forming outputs (two channels: channel 1 and channel 2) to first and second light output generating circuits 32 and 33, respectively. The circuits 32 and 33 are connected to a laser diode 34. In addition, there is provided pulse prohibition means 35 for prohibiting individually the generations of a first pulse, second pulse, ..., and nth pulse of each of the start part, intermediate part and end part of each channel.

The pulse prohibition means 35 is constituted by a great number of switches such as snap switches. As shown in Fig. 10, pulse prohibition means 35a is provided between AND gates 20a to 20n and monostable multivibrators 36a to 36n. The monostable multivibrators 36a to 36n are connected to an aggregate circuit 37, from which the channel 1 of the pulse forming output is outputted. Likewise, pulse prohibition means 35b is provided between the AND gates 20a to 20n and monostable multivibrators 38a to 38n. The monostable multivibrators 38a to 38n are connected to an aggregate circuit 39, from which the channel 2 of the pulse forming output is outputted.

Fig. 11 shows the timing and the light output of the laser diode 34 of the third embodiment. In this example, the mark length is 5τ, the width of the start part control signal A is 2τ, and the cycle of the pulse forming clock is $T = (1/2)\cdot\tau$.

Since in the third embodiment the cycle of the pulse forming clock is $T = (1/2)\cdot\tau$, it is effective that four pulse prohibition means 35 are for the start part, two for the end part and 16 for the intermediate part, as shown in Fig. 11(b). If the pulse prohibition means 35a and 35b of the channels 1 and 2 in Fig. 10 are set as shown by OX in Fig. 11(b), the pulse forming outputs of the channels 1 and 2 then become as shown in Fig. 11(c). Since the outputs of the channels 1 and 2 are connected respectively to the first and second light output generating circuits 32 and 33, the light output of the laser diode 34 comprises two leading pulses having second light outputs larger than normal and the remaining pulses having first light outputs of normal size, as shown in Fig. 11(d).

Thus, in this embodiment, by outputting a plurality of pulse forming outputs (a plurality of channels) from the pulse forming circuit 31 and by providing the pulse prohibition means 35 for prohibiting the generation of each pulse individually, not only the pulse width but also the light output can be varied, and consequently optimum writing conditions can be set more finely.

Although this embodiment has been described

with respect to 2 channels. 3 or more channels may also be provided in order to vary the light output more finely. In addition, the pulse prohibition means is not necessarily needed to be constituted by switches. For example, means for removing pulse generation means, or means for removing a connection can be used.

Fourth Embodiment

Figs. 12 and 13 illustrate a fourth embodiment of the present invention. In this embodiment, in order to correct the influence of the remaining heat from the previously written pit, the light output of the write start part pulse is controlled according to the space length immediately after the previously written pit. As the control signal, the mark length control signal F shown in the first embodiment is used. That is to say, this embodiment is substantially identical to the structure of the third embodiment of Fig. 9, except there is provided a light output control circuit 51 to which the mark length control signal F is inputted. The light output control circuit 51 is connected to the second light output generating circuit 33. On the basis of the mark length control signal F, the amplitude of the write start part pulse is varied by the light output control circuit 51 in accordance with the space length immediately after the previously written pit, as shown in Fig. 13, and consequently the light output is controlled finely. Therefore, this embodiment also can effectively correct the influence of the remaining heat.

Although only one reference signal E and one mark length control signal F have been described for convenience, a plurality of mark length control signals F_1 to F_n can be produced from a plurality of reference signals E_1 to E_n. In that case, the light output corresponding in size to each mark length control signal can be outputted at the light output control circuit 51, and consequently the light output can be controlled more finely.

Fifth Embodiment

Fig. 14 shows the result obtained by correcting the influence of the remaining heat by the first and second embodiments of the present invention. Figs. 15-17 show a fifth embodiment of the present invention.

In the first embodiment, in order to correct the influence of the remaining heat from the previously written mark, the mark write start position is controlled by increasing or decreasing the number of generated pulses in accordance with the space length immediately after the previous mark. Fig. 14 is used to explain the correction of the remaining heat as the second embodiment was applied to the first embodiment. That is to say, under the write pulse condition in which each pulse width of the above described favorable write pulse condition (pulse forming clock τ) is reduced to half, the correction of the remaining heat was made with the delay time of the third delay signal D_3 of 0.5τ and with the reference signal length of 6τ (the correction of the remaining heat is made only when the space length immediately before the mark length is between 3τ and 5τ). The "o" shown in Fig. 14 is a case where the correction of the remaining heat was not made, while the "Δ" is a case where the correction of the remaining heat was made at the above described condition. When the space length is between 3τ and 5τ, the written mark length is shortened by about 0.5τ by the correction. Since errors in the written mark lengths are within $\pm 0.5\tau$ which is a discriminative reference of a read signal, the correction of the remaining heat has been made effectively.

However, in this method, the resolution of the write start position is limited by the cycle of the pulse forming clock. Where a finer correction is required, for example, where the write start position is required to vary 10ns by 10ns each time the space length varies 1τ, a pulse forming clock of 10ns cycle (100 MHz frequency) is needed, and cannot be obtained with TTL presently in use. In addition, where the write start position is controlled each time the space length varies 1τ between 3τ and 11τ, nine reference pulses are needed and consequently the amount of hardware is increased.

Such a fine control of the write start position can be achieved by the fifth embodiment shown in Fig. 15. In Fig. 15, the pulse train control circuit in this embodiment is constituted by a passing path group 54 for a leading pulse (the first pulse of the start part shown in Fig. 3), space recognition means 55 for recognizing a space length, and passing-path selection means 56 for selecting a passing path of the leading pulse from the recognition result of the recognition means 55. The space recognition means 55 is constituted by a counter 57 for counting the space length at the rate of 1τ, inverters 58, 59, a delay circuit 60, a NAND gate 61, and AND gates 62a to 62n (decode circuits) to which the outputs of the counter 57 are inputted. In addition, the passing path group 54 is constituted by delay lines (DL) 63a to 63n connected in series which serve as the passing path of the leading pulse. The passing-path selection means 56 is constituted by AND gates 64a to 64n to which each space length and the outputs of the delay lines 63a to 63n are inputted, and a OR gate 65 as an aggregate circuit. From the OR gate 65 is outputted a trigger signal of the monostable multivibrator

21a of Fig. 3, as a leading pulse output.

In the structure as described above, assume that the inverted signal $\overline{D_1}$ of the first delay signal D_1 has been inputted to the enable terminal of the counter 57. If the signal $\overline{D_1}$ becomes "H" after the space part is inputted, then the counter 57 starts counting clocks. If the mark part is inputted after the space part, then the signal $\overline{D_1}$ becomes "L", and the content of the counter 57 immediately before the mark part is maintained. That is to say, the counter 57 functions as a memory which accumulates the data of the space length at the time the mark part is inputted. Therefore, by decoding the content of the countor 57, only one decoder output corresponding to the space length becomes "H" at the time the mark part has appeared. A 3 decoder output (corresponding to the space length 3τ) and 10 decoder output (corresponding to the space length 10τ) are shown in Fig. 16. These outputs are used to select the passing path of the leading pulse. The counter 57 is reset at the rise of the signal $\overline{D_1}$ and starts counting the next space length.

On the other hand, the leading pulse (first pulse of the start part) that is used to trigger the monostable multivibrator 21a shown in Fig. 3 is inputted to the delay lines 63a to 63n that are the passing path group 54, before the leading pulse is inputted to the monostable multivibrator 21a. The passing path group 54 is constituted by the delay lines 63a to 63n (DL_{11}, DL_{10}, ... DL_3), and the DL_{11}, DL_{10}, ... DL_3 correspond to the space lengths immediately before the mark lengths 11τ, 10τ, ..., and 3τ, respectively. Since the outputs of the delay lines 63a to 63n are connected to the AND gates 64a to 64n which are controlled by the outputs of the AND gates 62a to 62n, only a pulse which has passed the path of the delay time corresponding to the space length is taken out and triggers the monostable multivibrator 21a (Fig. 3). In this way, the space length immediately before the mark part is recognized, and the position of generation of the leading pulse is controlled according to the recognition.

By providing taps of 5ns with the delay lines 63a to 63n, the position of generation of the leading pulse can be controlled with this time resolution. As a result, a time resolution of 10ns and below can be achieved with a TTL presently in use.

Although in the above description only one passing-path selection means 56 is provided and the correction of the remaining heat has been made by delaying only the first pulse of the start part, the correction of the remaining heat can also be made by providing a plurality of passing-path selection means and delaying first to nth pulses of the start part. In that case only one space recognition means 55 is required. Moreover, the delay times of a plurality of passing path selection means corresponding to the first to nth pulses of the start part can be gradually varied such that when the space length is 3τ, the delay time of the first pulse is 150ns, the delay time of the second pulse is 140ns, ..., and the delay time of the nth pulse is (160 - 10n)ns. In addition, the delay times can be gradually varied such that when the space length is 10τ, the delay time of the first pulse is 20ns, the delay time of the second pulse is 15ns, ..., and the delay time of the nth pulse is (25 - 5n)ns. In that case an output pulse train as shown in Fig. 17 can be obtained, and consequently a finer correction of the remaining heat can be made.

Sixth Embodiment

Figs. 18 and 19 show a sixth embodiment of the present invention. Although the control of the leading pulse position based on the space length that has been described in the fifth embodiment is suited to a CD (compact disk) recording which is representative of a recording in a constant rotational line speed (i.e., Constant Linear Velocity), the control cannot be applied to a recording in a constant rotational angular speed (i.e., Constant Angular Velocity) such as a magneto-optical disk recording. Namely, in the recording in a constant rotational angular speed, the line speed becomes faster in the outer peripheral portion of the disk than in the central or inner portion, and therefore even if signals having the same lengths in time are recorded, the recorded length on the outer peripheral portion becomes longer. Therefore, the influence of the remaining heat becomes smaller in the outer peripheral portion than in the inner peripheral portion.

Hence, in the sixth embodiment, the delay times of the delay lines 63a to 63n are varied in accordance with the radius of gyration of the disk.

In the recording in a constant rotational angular speed, there is provided means for detecting the present position of the radius of gyration from a position of an optical head or an address recorded in a medium. This means is normally signals represented by binary notation. For this reason, in this embodiment radius position signals represented by binary signals are inputted to AND gates 71a to 71n that are used as decode circuits, as shown in Fig. 19. One of the outputs of the AND gates 71a to 71n that are used as the decoders for detecting the radius position, becomes "H". As shown in Fig. 18, the outputs S_1 to S_n of the AND gates 71a to 71n are inputted to AND gates $72A_1$ to $72A_n$, $72B_1$ to $72B_n$, ... , and $72N_1$ to $72N_n$ which are used as radius position selection gates. The other input terminals of the AND gates $72A_1$ to $72A_n$, $72B_1$ to

$72B_n$, ... , and $72N_1$ to $72N_n$ are connected to the output taps 1, 2, ... n of the delay lines 63a to 63n. In addition, the outputs of the AND gates $72A_1$ to $72A_n$, $72B_1$ to $72B_n$, ... , and $72N_1$ to $72N_n$ are inputted to AND gates 73a to 73n, respectively, as shown in Fig. 18. In the next step there is provided space recognition means 55 which is identical in part with the fifth embodiment. Therefore, by making "H" one of the outputs S_1 to S_n of the radius position selection gates, one of the output taps 1, 2, ... n of the delay lines 63a to 63n is selected. Only the leading pulse which has passed through the selected output tap is inputted to the delay line of the next step, and becomes a leading pulse output by subsequent processes.

Note that the delay time between the input of and the output tap of each of the delay lines 63a to 63n is not necessarily needed to be the same between the delay lines 63a to 63n, and can be set according to the characteristics of disk media. In addition, the selection means 56 for selecting a passing path according to the space length is identical in construction with that of the fifth embodiment.

Although in the above description the correction of the remaining heat has been made by the leading pulse (first pulse of the start part), it can also be made by providing a plurality of the circuits shown in Figs. 18 and 19 and using the first to nth pulses of the start part, as in the case of the fifth embodiment.

Seventh Embodiment

Figs. 20-27 show a seventh embodiment of the present invention. This embodiment performs the correction of the remaining heat based on the space length more finely than the embodiments described above.

A pulse train control circuit 80 of this embodiment shown in Fig. 21 is constituted by a space recognition circuit 81 and a time-condensation control circuit 82.

The space recognition circuit 80 is the same circuit as the space recognition means 55 shown in Fig. 15, and generates space length signals corrosponding to the space lengths 3τ to 11τ.

The time-condensation control circuit 82 is constituted by a voltage controlled delay circuit 83 and a delayed time control circuit 84. The voltage controlled variable delay circuit 83 varies its delay time in response to a control voltage applied thereto, and is constituted by a combined element of a variable capacity diode and an inductance which is called VCVDL (Voltage Controlled Variable Delay Line). In this embodiment two elements produced by JPC Co., Ltd. are used, and as shown in Fig. 22, a variable range of 1020ns to 700ns is obtained with respect to a control voltage of 0 to 15V.

Consider now a case where a serrate control voltage of 3τ length (690ns) shown in Fig. 23 was applied to the voltage controlled variable delay circuit 83. The delay time of the voltage controlled variable delay circuit 83 varies as shown in Fig. 24 with respect to the elapsed time of the abscissa. The pulse inputted to the voltage controlled variable delay circuit 83 at the timing of the elapsed time 0 is propagated through the circuit 83, but the delay time of the delay circuit 83 varies moment by moment as shown in Fig. 24 during the propagation. Therefore, the pulse is delayed by a mean value ((1020 + 700)/2 = 860ns), which is obtained by averaging the delay time (1020ns) of the delay circuit 83 at which the pulse is inputted and the delay time (700ns) in the stable state, and appears in the output terminal of the delay circuit 83. In addition, a pulse inputted at the elapsed time of 300ns is delayed by 790ns(=(880 + 700)/2), since the delay time of the delay circuit 83 at that time is 880ns. Thus, if a pulse is inputted more late from the time the serrate control voltage was applied, the delay time becomes shorter. However, for pulses inputted more than 690ns late, the delay time becomes 700ns at all times since a control voltage is no longer applied.

Fig. 25 shows an example of a pulse train which was time condensed according to the above described principles. The correction value of remaining heat at a 3τ space is 160ns, and the serrate control voltage corresponding to this is 15V and 690ns, as shown in Fig. 25(b). In addition, as the input pulse train, a pulse train of a mark length 4τ that was formed at favorable conditions (Fig. 25-(a)) was used.

The leading edge of the first pulse of the input pulse train is delayed, and outputted after 860ns. Since the trailing edge of the first pulse is inputted after 100ns, it is delayed by (974 + 700)/2 = 837ns in accordance with the above described principles, and outputted at the time of 837 + 100 = 937ns. Consequently, the first pulse width of the output pulse train becomes 937 - 860 = 77ns. Likewise, the leading edge of the second pulse becomes 948ns, the trailing edge 1025ns and the pulse width 77ns. In the same way, the leading edge and width of the third pulse become 1036ns and 62ns. The leading edge and width of the fourth pulse become 1125ns and 46ns. The leading edges of the fifth and sixth pulses become 1213ns and 1301ns, respectively, and the widths become 46ns and 39ns, respectively. At the time the seventh pulse is inputted, the control voltage has become stable. Therefore, the seventh and eighth pulses are delayed by 700ns and outputted. In this way, the output pulse train shown in Fig. 25(c) is

obtained. In fact, a pulse train composed of various mark lengths and space lengths is inputted, but the position of the trailing edge of the last pulse is maintained at a position delayed by 700ns from the input pulse. That is to say, while the relationship between the mark length and space length of the input signal is being maintained, only pulse train of the part corresponding from the leading edge of each pulse to the width of the serrate control voltage is time condensed for the correction of the remaining heat.

In the method of the fifth embodiment shown in Fig. 17, even if the first, second, third and fourth pulses were respectively delayed 160ns, 150ns, 140ns and 130ns to perform the correction of the remaining heat, only space part would be condensed and each pulse width would not be varied. On the other hand, the seventh embodiment is characterized in that each pulse width and each space part are both condensed at the same rate.

In the input pulse train shown in Fig. 25(a), the sum of the pulse widths is 590ns, and the rate of the sum of the pulse widths to the length of the pulse train (pulse formation rate) is about 67%. In the method of the fifth embodiment shown in Fig. 17, the sum of the pulse widths is the same, and the length of the pulse train becomes 885 - 160 = 725ns. Therefore, the pulse formation rate is 590/725 = 0.81 (81%) and becomes larger than that (67%) of the input pulse train. On the other hand, since in the seventh embodiment the sum of the pulse widths is 487ns, the pulse formation rate becomes 487/725 = 0.67 (67%) and equal to that (67%) of the input pulse train.

It can be considered that the pulse formation rate is the energy density of the write laser beam. Therefore, if the pulse formation rate is maintained to be the same as the input pulse train which is a favorable pulse condition, the pit can be written more accurately even when the correction of the remaining heat has been made.

Although the correction of the remaining heat has been made to the start part pulse, it can also be made to the intermediate part. That is to say, in the correction of the remaining heat by the time condensation of the seventh embodiment, even if a pulse train of any shape and combination were inputted, the input pulse train could be condensed similarly over the entire region of the correction range. Therefore, as in the embodiments described above, the pulse train is not always needed to be divided into three parts of the start part, intermediate part and end part. For example, even when each of the mark lengths 3τ to 11τ is constituted by a pulse train of an entirely different combination, the correction of the remaining heat can be made effectively.

Fig. 26 shows an example of the delay-time control circuit 84. The delay-time control circuit 84 is constituted by a correction-range set circuit 90 for producing from the above described first delay signal D_1 a pulse having a width equal to the width of the control voltage, a serrate wave generating circuit 91 for converting the pulse to a serrate wave, a delay-time set circuit 92 for setting a delay time for a favorable correction of the remaining heat in accordance with the results of the space recognition means 55 and 81, and a subtraction circuit 93.

The correction-range set circuit 90 comprises a monostable multivibrator 94 and generates a pulse (Fig. 27(b)) having a pulse width which synchronizes with the rise of each mark part of the input signal D_1 as shown in Fig. 27(a). The pulse width can be set by a variable resistor 94R, and is 3τ - (690ns) in this embodiment.

The pulse is converted as shown in Fig. 27(c) by the serrate-wave generating circuit 91 which comprises a differentiation circuit 95, and inputted to the delay-time set circuit 92. The linearity of the serrate wave can be varied by adjusting a feedback resistance Rf of an operational amplifier.

The delay-time set circuit 92 is constituted by nine sets of an amplifier 96 and switch means 97 corresponding to each space length. Since the amplification factor of each amplifier 96 is determined by Rf/R, the peak value of an output serrate wave can be varied by varying the feedback resistances Rf3 to Rf11 of the amplifiers 96. The output of each amplifier 96 can be set as shown in Fig. 27(d). The output of each amplifier 96 is connected to the switch means 97 such as an analog switch, which is controlled by a space length signal outputted from the above described space recognition means 55 or 81. Therefore, in the output side of the switch means 97 appears only one serrate wave having a peak voltage corresponding to the space length (correction value of remaining heat).

The subtraction circuit 93 is an inversion amplifier 93 having a gain of one time, and constituted by an operational amplifier 98 and resistances Re and Rs. This subtraction circuit 93 outputs a difference between the input terminals. Since the plus input terminal is connected to 15V, a waveform obtained by subtracting the serrate wave inputted to the minus input terminal from 15V is outputted as shown in Fig. 27(e). The resistance Re serves to maintain the minus input terminal to be 0V, when all the switch means 97 are in the off positions. The output of the subtraction circuit 93 is applied as a serrate control voltage to the voltage controlled delay circuit 83 to perform the time condensation described above.

The operational amplifier used in each circuit described above is one which generates an output voltage of 15V and above, and it is preferable that

the amplifier is of the high speed and high slew rate type. For example, it is preferable that LH0032CG and the like be used.

Although in the above example the correction-range set circuit 90 comprises the monostable multivibrator 94 and the serrate-wave generating circuit 91 comprises the differentiation circuit 95, the present invention is not limited to this. For example, by using a serrate wave which generates in the base side of a monostable multivibrator having an asymmetrical time constant, it is possible to incorporate the two circuits in one.

The favorable result of the correction of the remaining heat in accordance with this embodiment is shown in Fig. 20. In Fig. 20, "o" is data obtained when the correction is not made, and "Δ" is data obtained when the correction was made. The input or write pulse train used is the favorable pulse train shown in Fig. 25(a). The correction value (maximum correction) is 160ns for a space length 3τ, 100ns for a space length 4τ, 60ns for a space length 5τ, 30ns for a space length 6τ, 20ns for a space length 7τ, and 10ns for space lengths of 8τ and above. The result is slightly nonlinear, as shown in Fig. 20, but the correction of the remaining heat has been performed almost perfectly.

Eighth Embodiment

Figs. 28 and 29 show an eighth embodiment of the present invention. It has been described that in the seventh embodiment the range of the correction of the remaining heat (the width of the serrate-wave control voltage) is 3τ. The reason is that the minimum mark length of a CD signal is 3τ and that if the correction range is above 5τ, the end pulse position of the pulse train for a mark length 3τ will be largely delayed from a specified position. However, there are some cases where with respect to a pulse train of a longer mark length (for example), above 7τ), a wider range of correction (for example, above 5τ) is required to be made to obtain a pulse train very similar to an input pulse train. In this embodiment, the end pulse of a pulse train of a shorter mark length appears in the specified position even when a wider range of correction was made.

The structure of a delay-time control circuit of this embodiment is shown in Fig. 28. The delay-time control circuit is different in part from the circuit of Fig. 26, and characterized in that it has a switch 102 for selectively connecting the minus input side of a subtraction circuit 101 to an electric potential of 0 V, a switch control circuit 103 for controlling the switch 102, and an inverter 104 for inverting a first delay signal D_1 and inputting the same to the switch control circuit 103. In the switch control circuit 103, a switch control signal such as a first delay signal $\overline{D_1}$ is inputted. The first delay signal $\overline{D_1}$ becomes "Low" when a mark length appears and "High" when a space length appears. Therefore, by adjusting the first delay signal $\overline{D_1}$ at the switch control circuit 103 to control the switch 102, the voltage of the minus input side of the subtraction circuit 101 can be always set to 0 V immediately before the mark length ends.

Consider a case where a pulse width of 4τ is set in the above described correction-range set circuit 90 and a pulse train of a mark length 3τ is inputted to the above described voltage controlled delay circuit 83. The input waveform of the subtraction circuit 101 becomes the waveform shown in Fig. 29(a), and the output waveform becomes the waveform shown in Fig. 29(b). Therefore, if the output waveform of the subtraction circuit 101 is applied to the above described voltage controlled delay circuit 83, then the delay time of the delay circuit 83 returns back to a stable state immediately before the end pulse of the pulse train of the mark length 3τ is inputted. Accordingly, the end pulse is outputted at the position of (input time + 700ns), as in the case of the end pulses of the pulse trains of the other mark lengths.

With respect to pulse trains of longer mark lengths than the pulse width set in the above-described correction-range set circuit 90, there is no influence, since the above-described switch 102 has been switched off until the control signal of the set pulse width becomes a stable state.

An embodiment of the present invention provides a write control method for writing optical disk data wherein pits are written by a write signal composed of mark signal parts and space signal parts, and the length of each pit represents the optical disk data, comprising the steps of: converting the mark signal parts to pulses and generating a series of pulse trains which correspond to lengths of the mark signal parts, respectively; controlling length and/or amplitude of each of the pulse trains in accordance with length of the space signal part immediately before the mark signal part; and applying successively the controlled pulse trains to laser irradiation means so that the pits are written.

Claims

1. A write control method for writing optical disk data wherein pits are written on a medium by a write signal composed of mark signal parts and space signal parts, the length of each pit representing the optical disk data, comprising the steps of:
converting the mark signal parts to pulses and generating a series of pulse trains which correspond to the lengths of the mark signal parts,

respectively;
controlling length and/or amplitude of or in each of the pulse trains in accordance with the length of the space signal part immediately before the mark signal part concerned; and
applying successively the controlled pulse trains to laser irradiation means so that the pits are written.

2. A method as claimed in claim 1, wherein each mark signal part is divided into three parts, comprising: (a) a start part, serving to raise the temperature of the medium rapidly to a writable temperature, (b) an intermediate part, serving to balance heat radiation from the medium at the raised temperature, and (c) an end part, serving to provide a fall in temperature of the medium in accordance with predetermined conditions for completion of laser irradiation of the medium;
and wherein
the three parts of each mark signal part are converted to pulses with pulse widths in each part providing for favourable writing conditions, for providing the pulse trains;
and wherein
the number of pulses in the intermediate parts of different mark signal parts varies in accordance with variations in length of mark signal parts concerned.

3. A method as claimed in claim 1 or 2, wherein a part or the whole of each pulse train is time condensed in accordance with the length of the space signal part immediately before the mark signal part concerned, in such a manner that the position of an end pulse of each resulting controlled pulse train is the same.

4. A method as claimed in claim 1, 2 or 3, the pulse formation rate of a controlled pulse train is maintained approximately equal to the pulse formation rate of a mark signal part.

5. Write control apparatus for writing optical disk data wherein pits are written on a medium by a write signal composed of mark signal parts and space signal parts, the length of each pit representing the optical disk data, comprising:
pulse forming means for converting the mark signal parts to pulses and generating a series of pulse trains which correspond to the lengths of the mark signal parts, respectively;
pulse train control means for controlling length and/or amplitude of or in each of the pulse trains in accordance with the length of the space signal part immediately before the mark signal part concerned, and
means for applying successively the controlled pulse trains to laser irradiation means so that the pits can be written.

6. Apparatus as claimed in claim 5, further comprising space recognition means for recognising the length of a space signal part immediately before a mark signal part, and wherein the pulse train control means provide time condensing means for time condensing a part or the whole of each pulse train in dependence upon the recognition result from the space recognition means in such a manner that the position of an end pulse of each resulting controlled pulse train is the same.

7. Apparatus as claimed in claim 6, wherein the time condensing means is constituted by a voltage controlled variable delay circuit and a delay-time control circuit operable to supply a serrate control voltage to the voltage controlled variable delay circuit.

8. Apparatus as claimed in claim 7, wherein the voltage controlled variable delay circuit is constituted by a variable capacity diode and an inductance.

9. Apparatus as claimed in claim 7 or 8, wherein the delay-time control circuit includes:
a serrate wave generating circuit for generating a serrate wave having a predetermined time width,
a delay-time set circuit for amplifying said serrate wave and setting a peak voltage of said serrate wave, the delay-time set circuit being constituted by a plurality of amplifiers, and
switch means for selecting an output of said delay-time set circuit in accordance with the recognition result from the space recognition means.

10. Apparatus as claimed in claim 9, wherein the delay-time control circuit further includes:
a switch connected to an output of said delay-time set circuit for selectively connecting a voltage of said output to a predetermined electric potential, and
a switch control circuit for controlling switch timing of said switch.

11. Apparatus as claimed in claim 9 or 10, wherein said serrate wave generating circuit is constituted by a monostable multivibrator for generating a pulse having a predetermined time width, and a differentiation circuit for differentiating an output of the monostable multivibrator.

12. Apparatus as claimed in claim 5, further comprising:
first delay means for delaying each mark signal part by a delay time within a first predetermined range,
second delay means for further delaying each mark signal, delayed by the first delay means, by a delay time within a second predetermined range,
control signal generating means for generating a start part control signal, an intermediate part control signal, and an end part control signal from outputs of the first and second delay means;
and wherein the pulse forming means are operable such that each mark signal part is divided into three parts, comprising: (a) a start part, serving to raise the temperature of the medium rapidly to a

writable temperature, (b) an intermediate part, serving to balance heat radiation from the medium at the raised temperature, and (c) an end part, serving to provide a fall in temperature of the medium in accordance with predetermined conditions for completion of laser irradiation of the medium.

13. Apparatus as claimed in claim 12, further comprising means for setting pulse width of each pulse in the pulse trains independently.

14. Apparatus as claimed in claim 12 or 13, wherein the pulse forming means are operable to provide pulse forming outputs in a plurality of channels, and further comprise pulse prohibition means operable to prohibit independently generation of pulses of a start part, an intermediate part and an end part of the pulse forming output of each channel.

15. Apparatus as claimed in claim 14, wherein the means for applying successively the controlled pulse trains to laser irradiation means, so that the pits can be written, comprises a plurality of light output generating circuits to which the pulse forming outputs of the plurality of channels are connected respectively, each such circuit providing a different light output.

16. Apparatus as claimed in claim 12, 13, 14 or 15, wherein the cycle of a pulse forming clock of the pulse forming means is shorter than that of a basic clock of the write signal.

17. Apparatus as claimed in claim 12, 13, 14 or 15, wherein the pulse train control means provides a reference signal of a predetermined length, and is operable to compare the reference signal with the length of a space signal part immediately before the mark signal part concerned, to produce a mark length control signal and to control the pulse trains in dependence upon the mark length control signal.

18. Apparatus in claimed in claim 17, wherein the pulse train control means provide a plurality of reference signals.

19. Apparatus as claimed in claim 17, wherein the light output provided in relation to the start part of a mark signal part is controlled in dependence upon the mark length control signal.

20. Apparatus as claimed in claim 12, wherein the pulse train control means includes:
a set of passing path groups constituted by a plurality of passing paths which have a predetermined passing time and arranged for passing a start part pulse,
space recognition means for recognising length of a space signal part immediately before the mark signal part concerned, and
passing path selection means for selecting the passing path of the start part pulse in dependence upon the recognition result from the space recognition means.

21. Apparatus as claimed in claim 20, wherein the passing time of said passing paths varies according to radial writing position on the optical disk medium.

22. Apparatus as claimed in claim 20 or 21, having a plurality of such sets of passing path groups, of different maximum passing times.

23. Apparatus as claimed in claim 20, 21 or 22, wherein amplitude of output of a pulse train is controlled in dependence upon the recognition result from the space recognition means.

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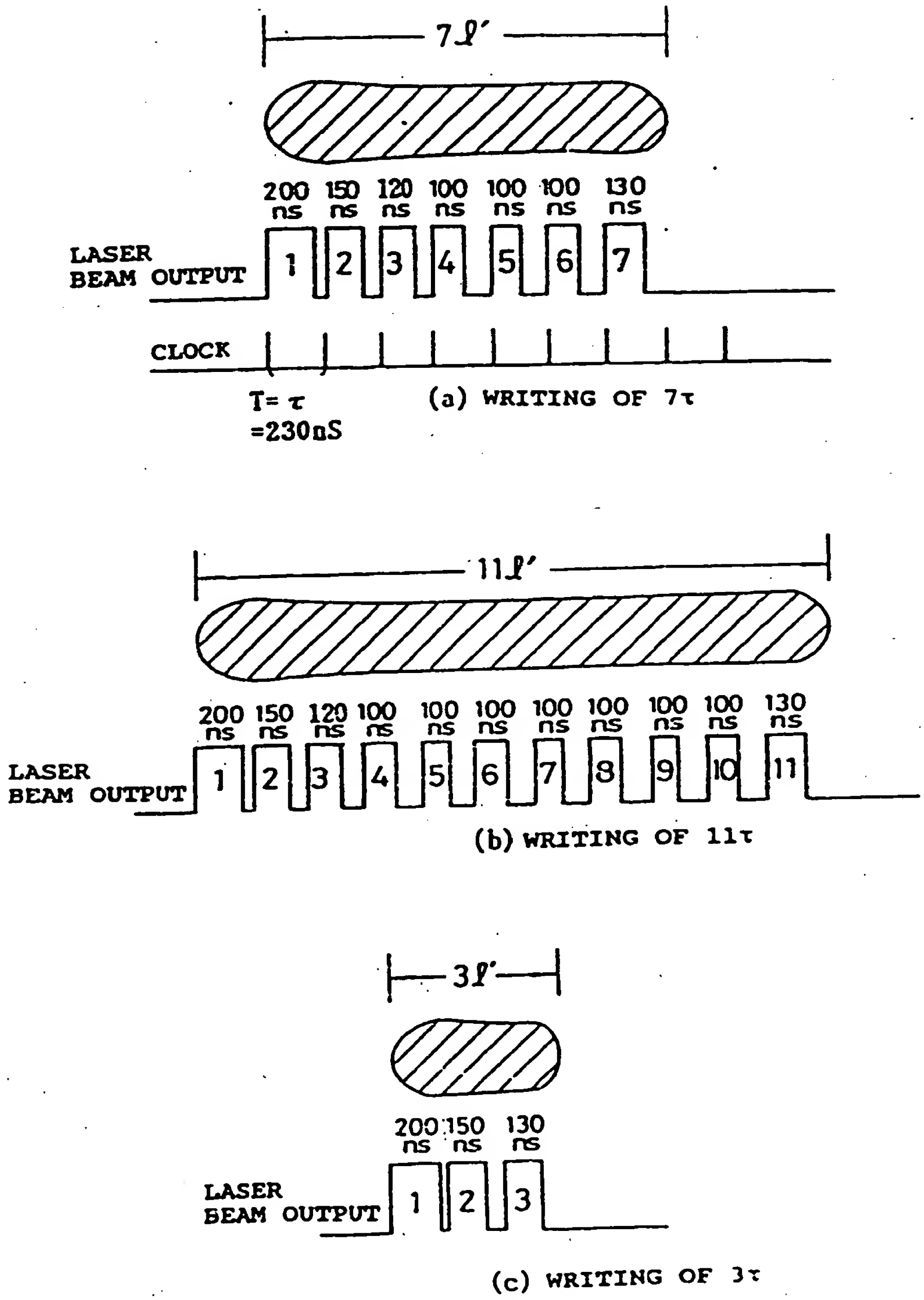


FIG. 1

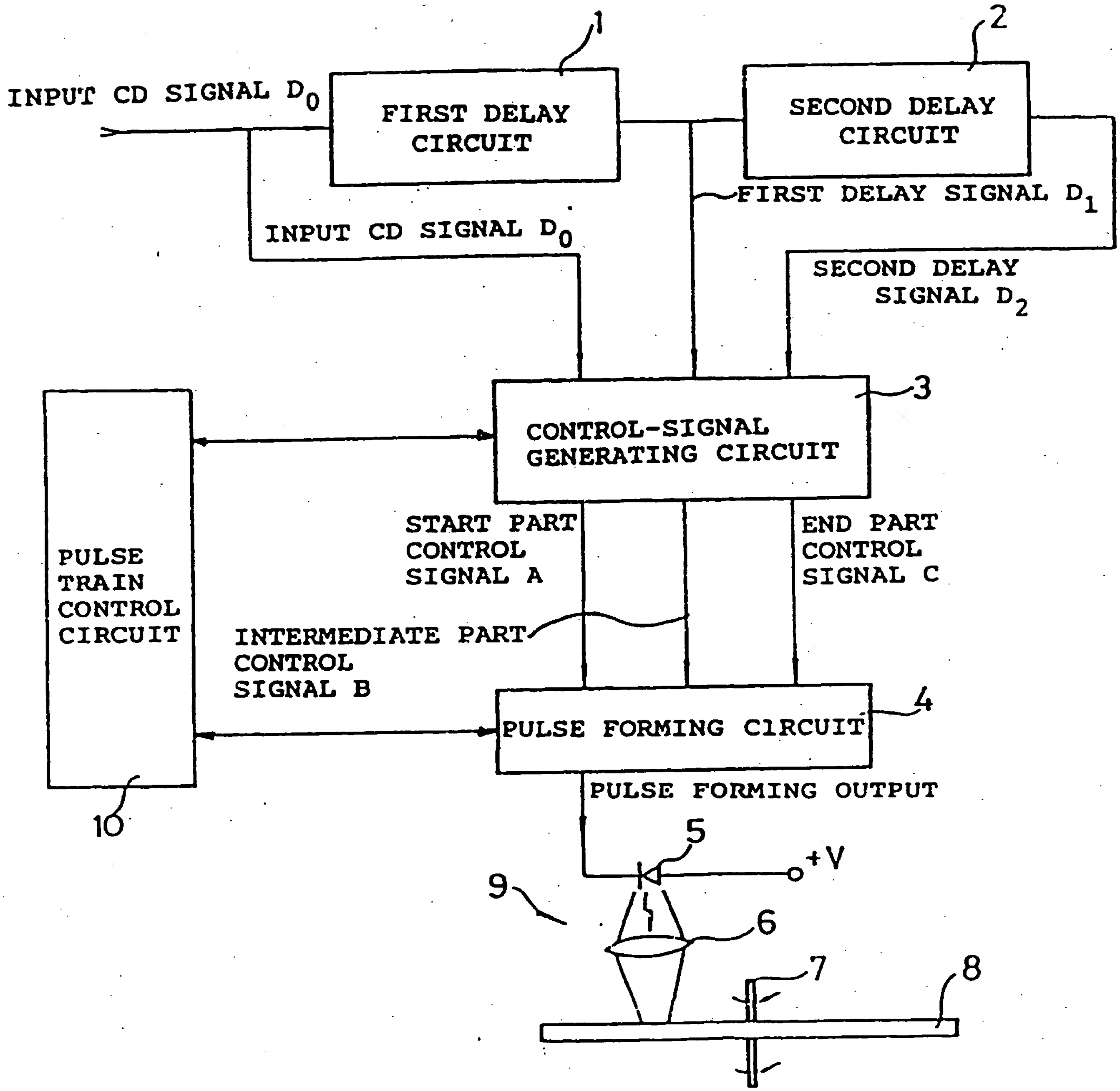

INPUT CD SIGNAL D_0
FIRST DELAY CIRCUIT
1
SECOND DELAY CIRCUIT
2
FIRST DELAY SIGNAL D_1
INPUT CD SIGNAL D_0
SECOND DELAY SIGNAL D_2
CONTROL-SIGNAL GENERATING CIRCUIT
3
PULSE TRAIN CONTROL CIRCUIT
START PART CONTROL SIGNAL A
END PART CONTROL SIGNAL C
INTERMEDIATE PART CONTROL SIGNAL B
PULSE FORMING CIRCUIT
4
PULSE FORMING OUTPUT
10
5
+V
9
6
7
8

FIG. 2

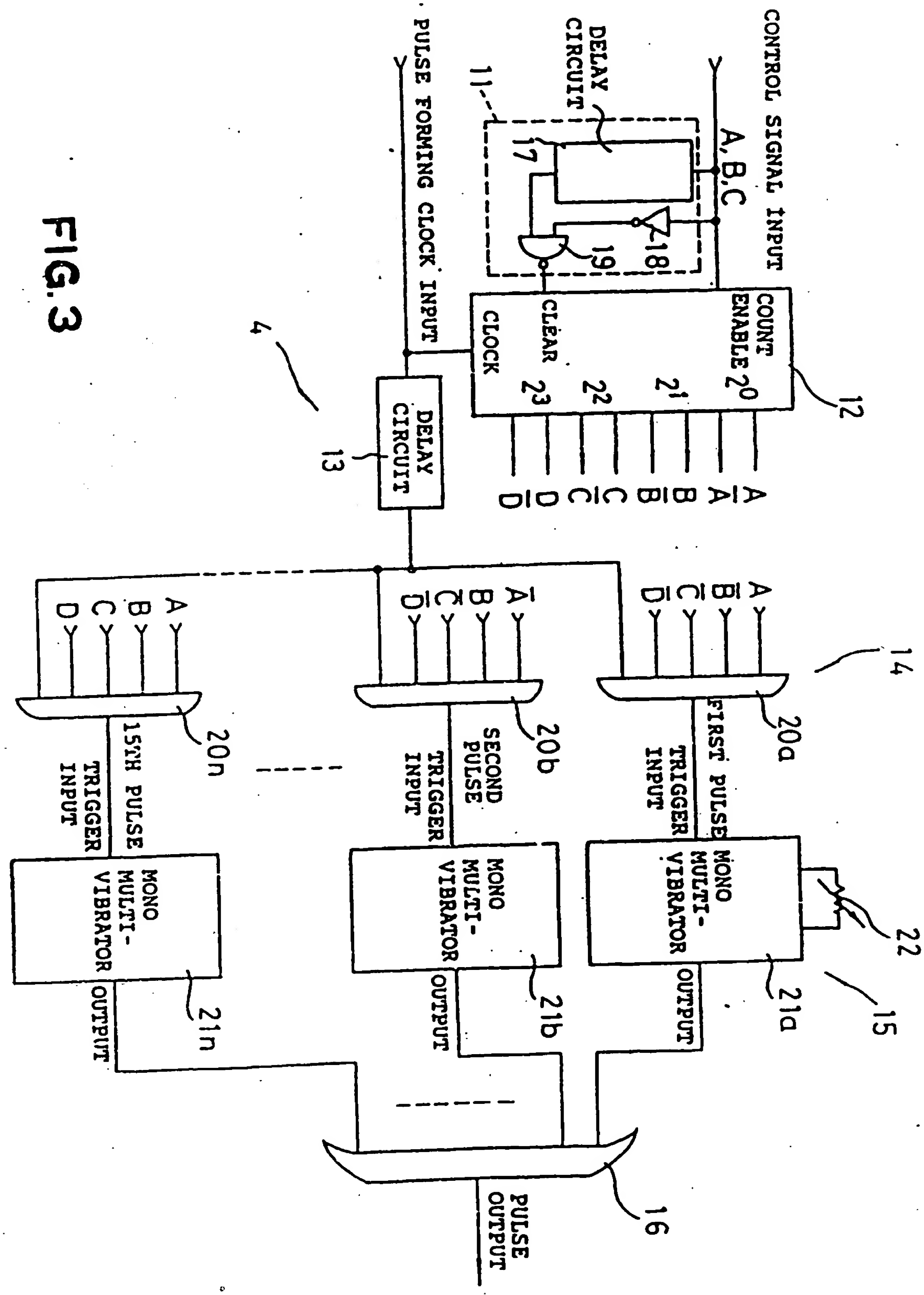

CONTROL SIGNAL INPUT
A, B, C
DELAY CIRCUIT
11
17
18
19
COUNT ENABLE
CLEAR
CLOCK
12
2^0
2^1
2^2
2^3
A
$\bar{A}$
B
$\bar{B}$
C
$\bar{C}$
D
$\bar{D}$
PULSE FORMING CLOCK INPUT
4
DELAY CIRCUIT
13
14
20a
20b
20n
FIRST PULSE
SECOND PULSE
15'TH PULSE
TRIGGER INPUT
MONO MULTI-VIBRATOR
OUTPUT
21a
21b
21n
22
15
16
PULSE OUTPUT

FIG. 3

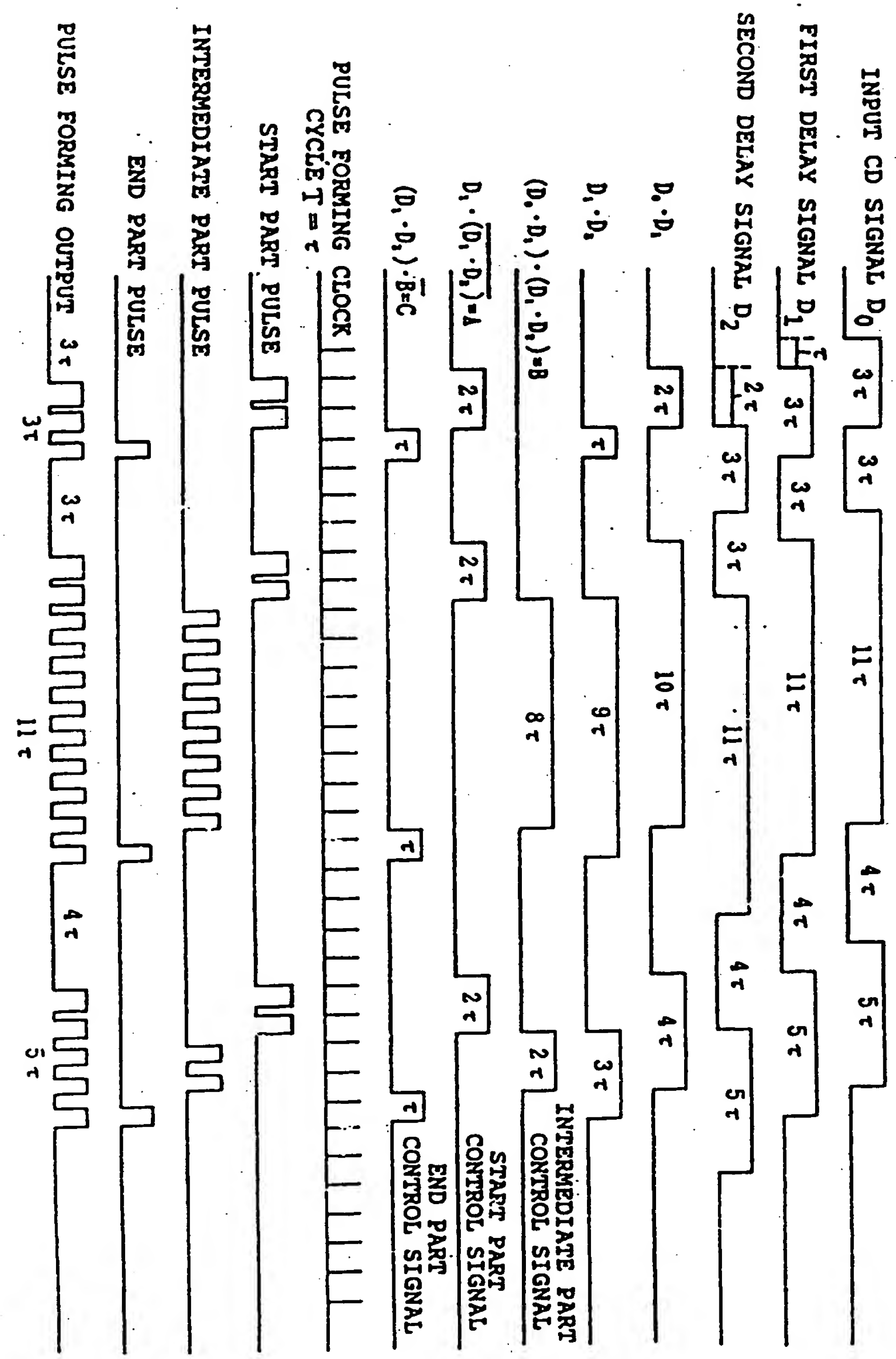

INPUT CD SIGNAL D_0
FIRST DELAY SIGNAL D_1
SECOND DELAY SIGNAL D_2
$D_0 \cdot D_1$
$D_1 \cdot D_2$
$(D_0 \cdot D_1) \cdot (D_1 \cdot D_2) = B$
$D_0 \cdot (\overline{D_1 \cdot D_2}) = A$
$(D_0 \cdot D_1) \cdot \overline{B} = C$
PULSE FORMING CLOCK
CYCLE T = τ
START PART PULSE
INTERMEDIATE PART PULSE
END PART PULSE
PULSE FORMING OUTPUT
INTERMEDIATE PART CONTROL SIGNAL
START PART CONTROL SIGNAL
END PART CONTROL SIGNAL
3τ
11τ
4τ
5τ
2τ
10τ
9τ
8τ
τ

FIG.4

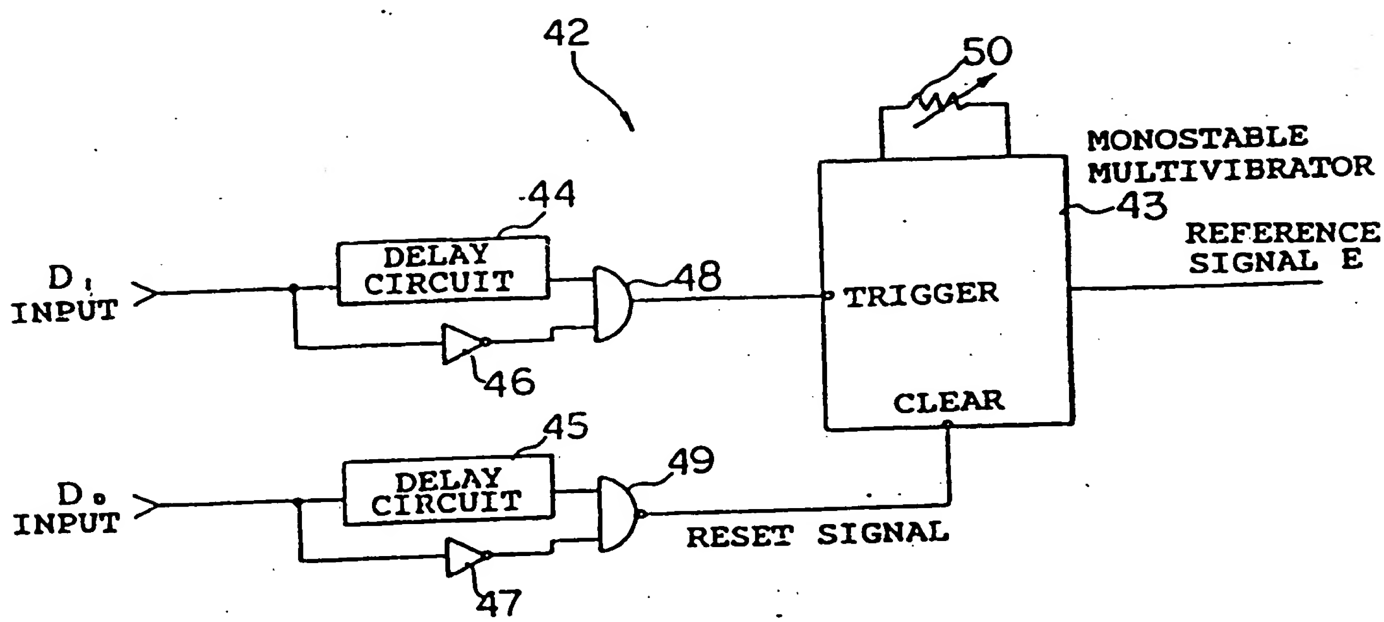

42
50
MONOSTABLE
MULTIVIBRATOR
43
REFERENCE
SIGNAL E
44
DELAY
CIRCUIT
48
TRIGGER
D1
INPUT
46
CLEAR
45
49
DELAY
CIRCUIT
D0
INPUT
RESET SIGNAL
47

FIG. 5

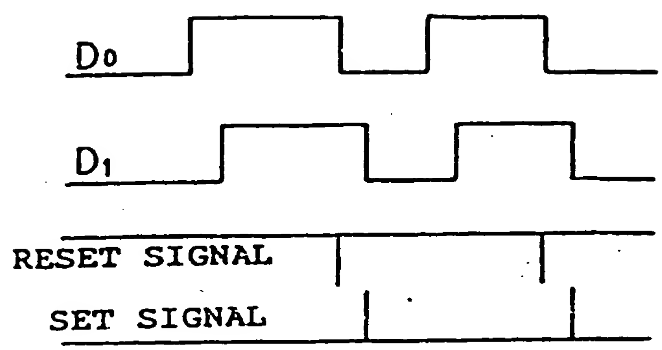


FIG. 6

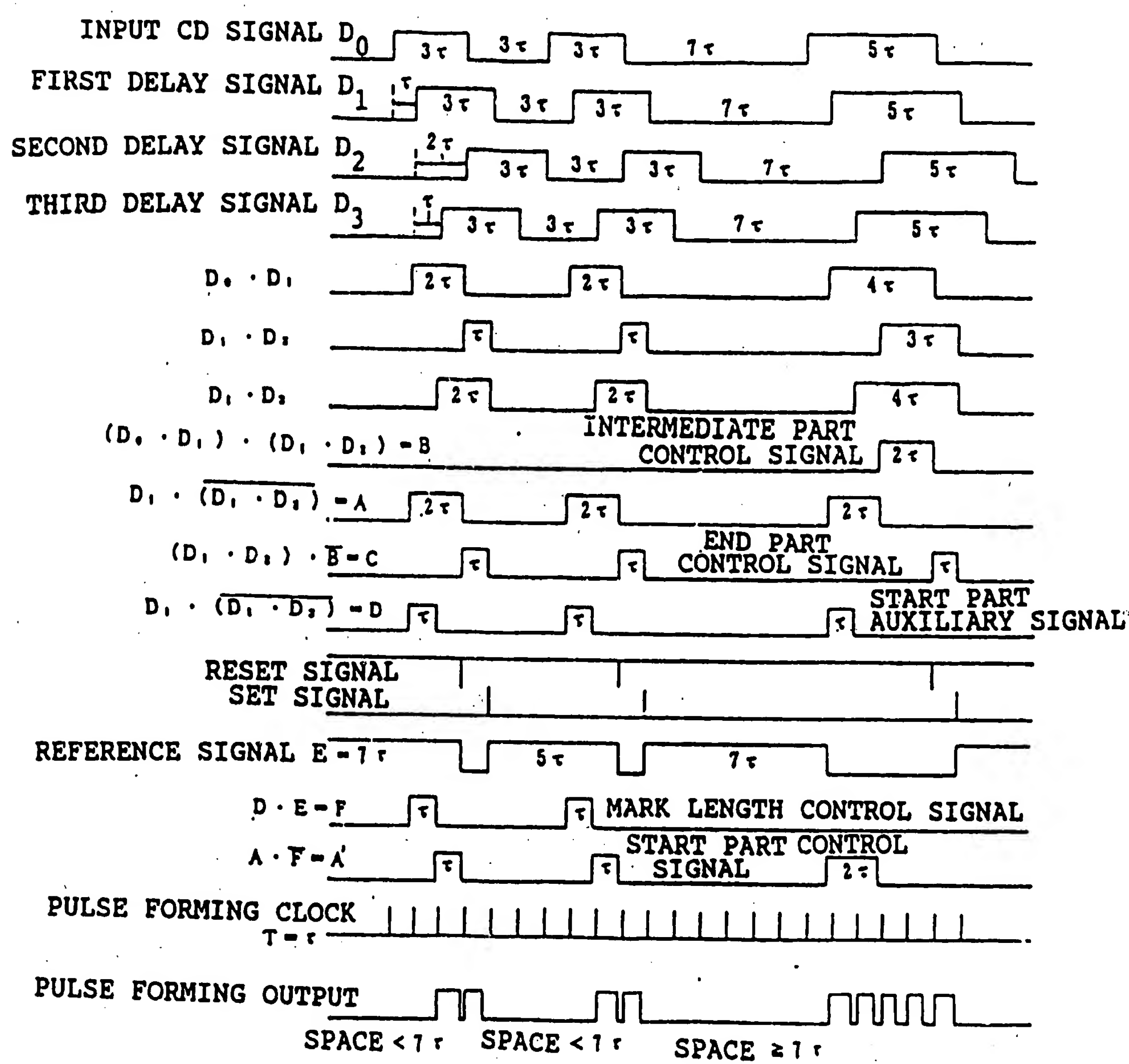

INPUT CD SIGNAL D0
FIRST DELAY SIGNAL D1
SECOND DELAY SIGNAL D2
THIRD DELAY SIGNAL D3
INTERMEDIATE PART CONTROL SIGNAL
END PART CONTROL SIGNAL
START PART AUXILIARY SIGNAL
RESET SIGNAL
SET SIGNAL
REFERENCE SIGNAL E = 7τ
MARK LENGTH CONTROL SIGNAL
START PART CONTROL SIGNAL
PULSE FORMING CLOCK
T = τ
PULSE FORMING OUTPUT
SPACE < 7τ
SPACE < 7τ
SPACE ≥ 7τ

FIG. 7

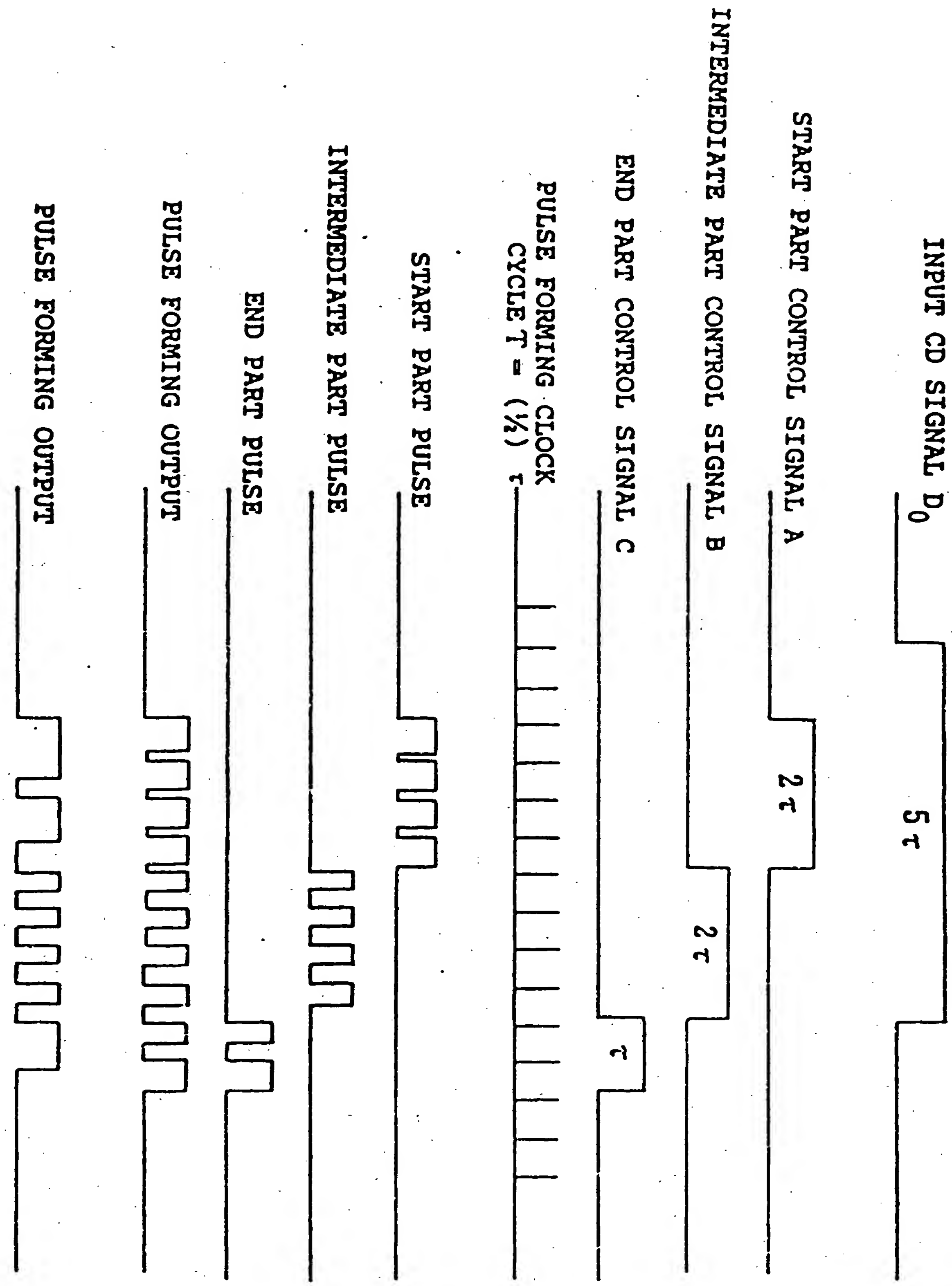

INPUT CD SIGNAL D_0
5τ
START PART CONTROL SIGNAL A
2τ
INTERMEDIATE PART CONTROL SIGNAL B
2τ
END PART CONTROL SIGNAL C
τ
PULSE FORMING CLOCK
CYCLE T = (½) τ
START PART PULSE
INTERMEDIATE PART PULSE
END PART PULSE
PULSE FORMING OUTPUT
PULSE FORMING OUTPUT

FIG.8

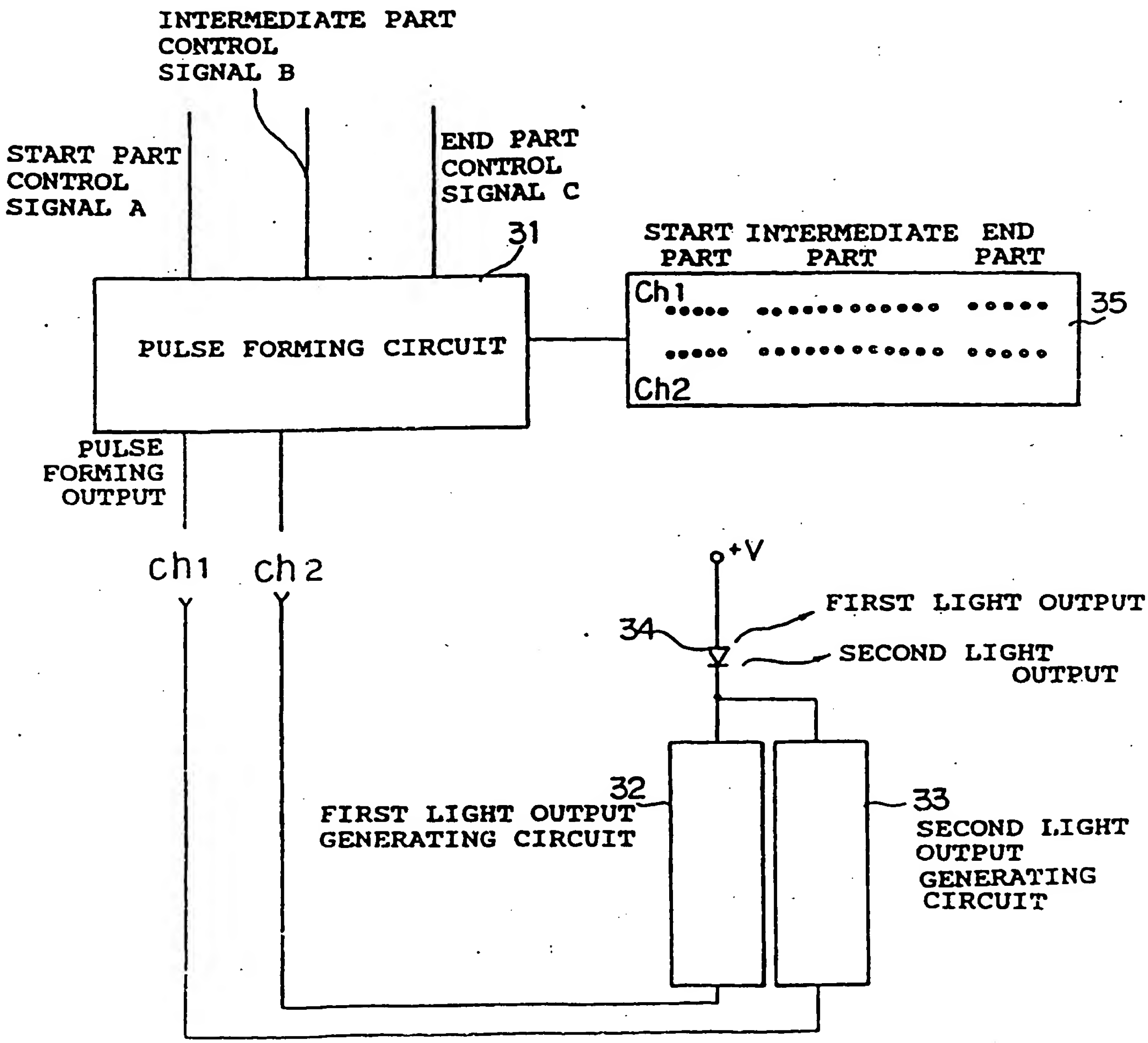
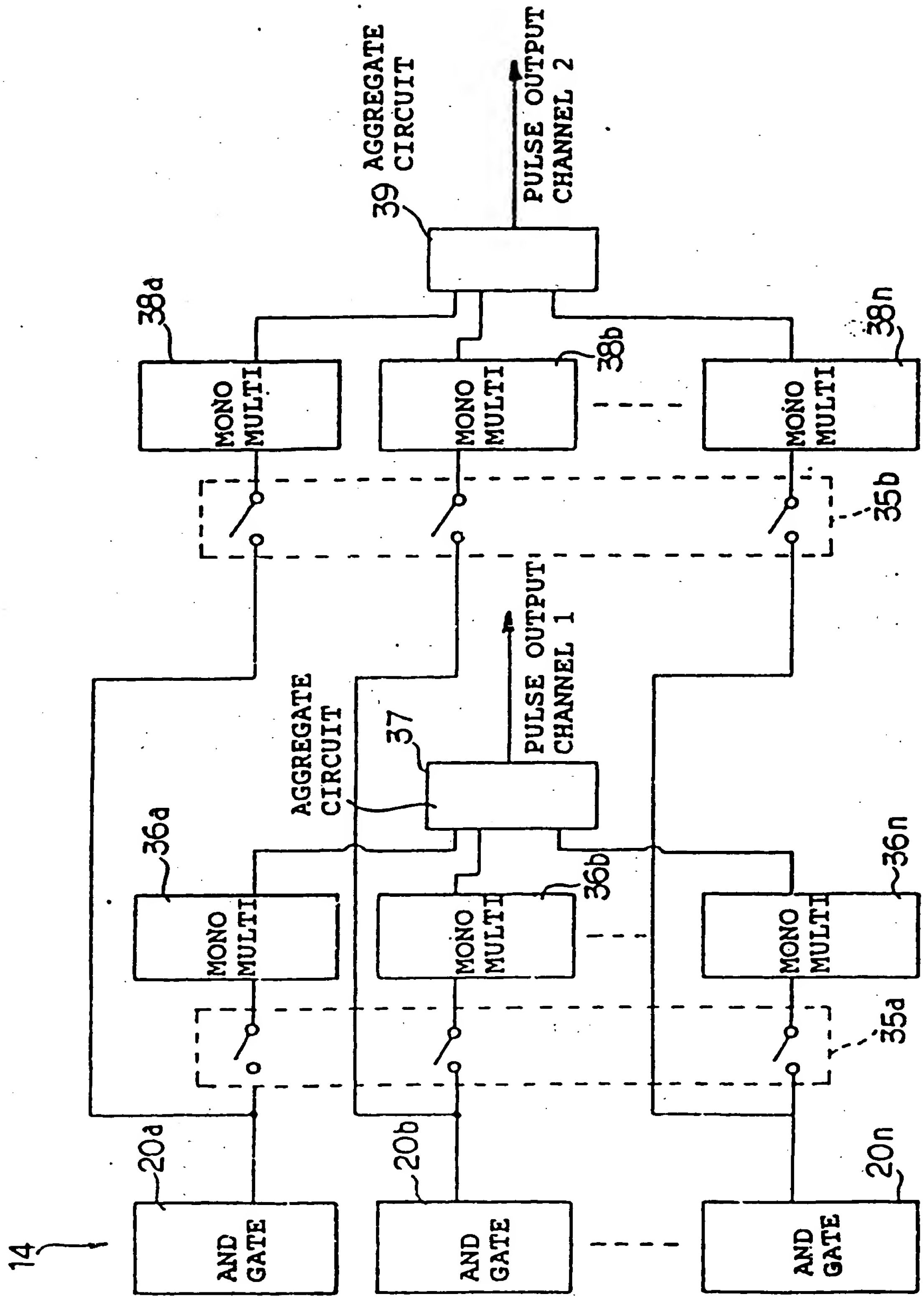

INTERMEDIATE PART CONTROL SIGNAL B
START PART CONTROL SIGNAL A
END PART CONTROL SIGNAL C
31
PULSE FORMING CIRCUIT
START PART
INTERMEDIATE PART
END PART
Ch1
Ch2
35
PULSE FORMING OUTPUT
ch1
ch2
+V
34
FIRST LIGHT OUTPUT
SECOND LIGHT OUTPUT
32
FIRST LIGHT OUTPUT GENERATING CIRCUIT
33
SECOND LIGHT OUTPUT GENERATING CIRCUIT

FIG. 9



14
AND GATE
20a
AND GATE
20b
AND GATE
20n
35a
MONO MULTI
36a
MONO MULTI
36b
MONO MULTI
36n
AGGREGATE CIRCUIT
37
PULSE OUTPUT CHANNEL 1
35b
MONO MULTI
38a
MONO MULTI
38b
MONO MULTI
38n
39 AGGREGATE CIRCUIT
PULSE OUTPUT CHANNEL 2

FIG.10

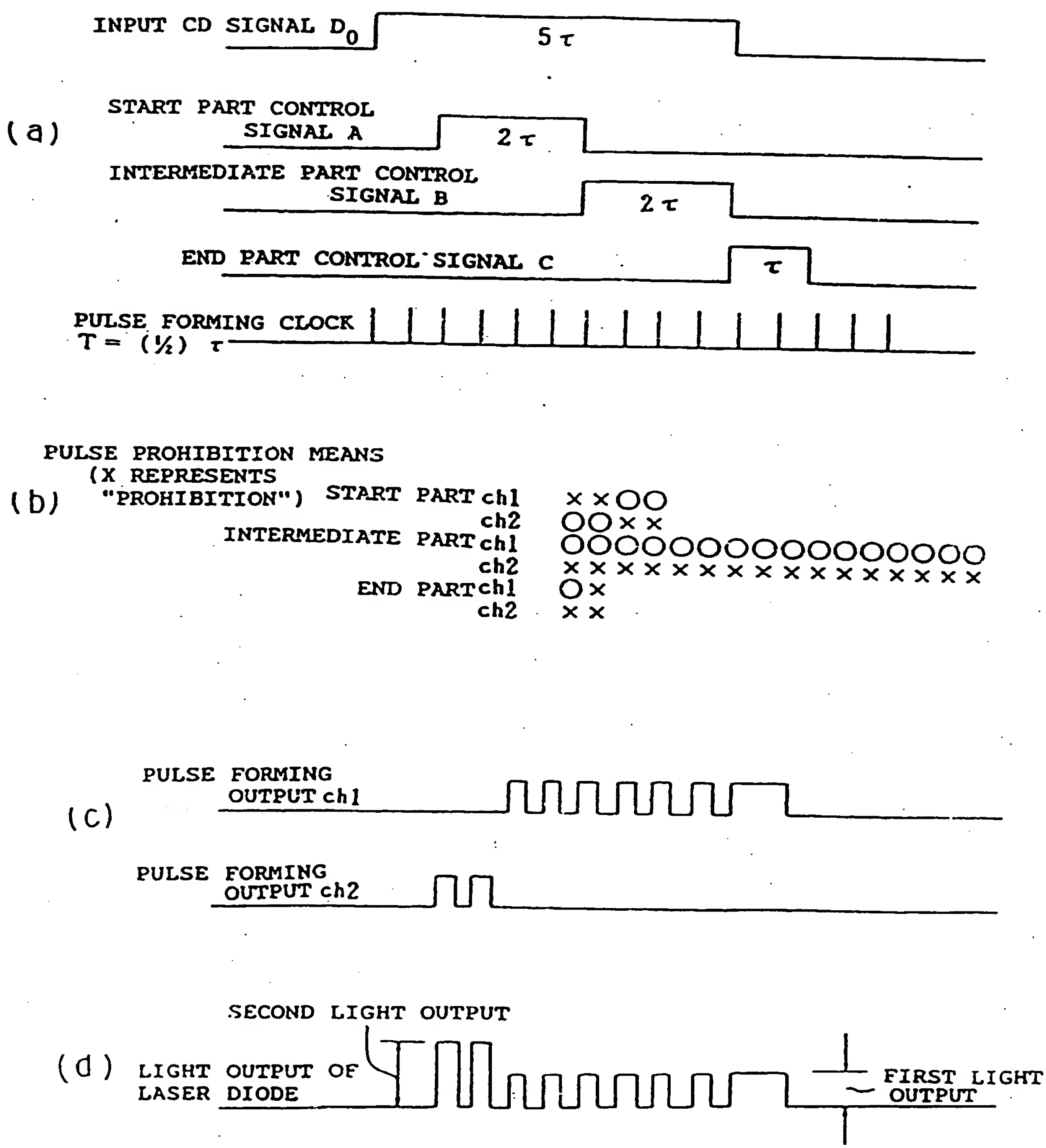
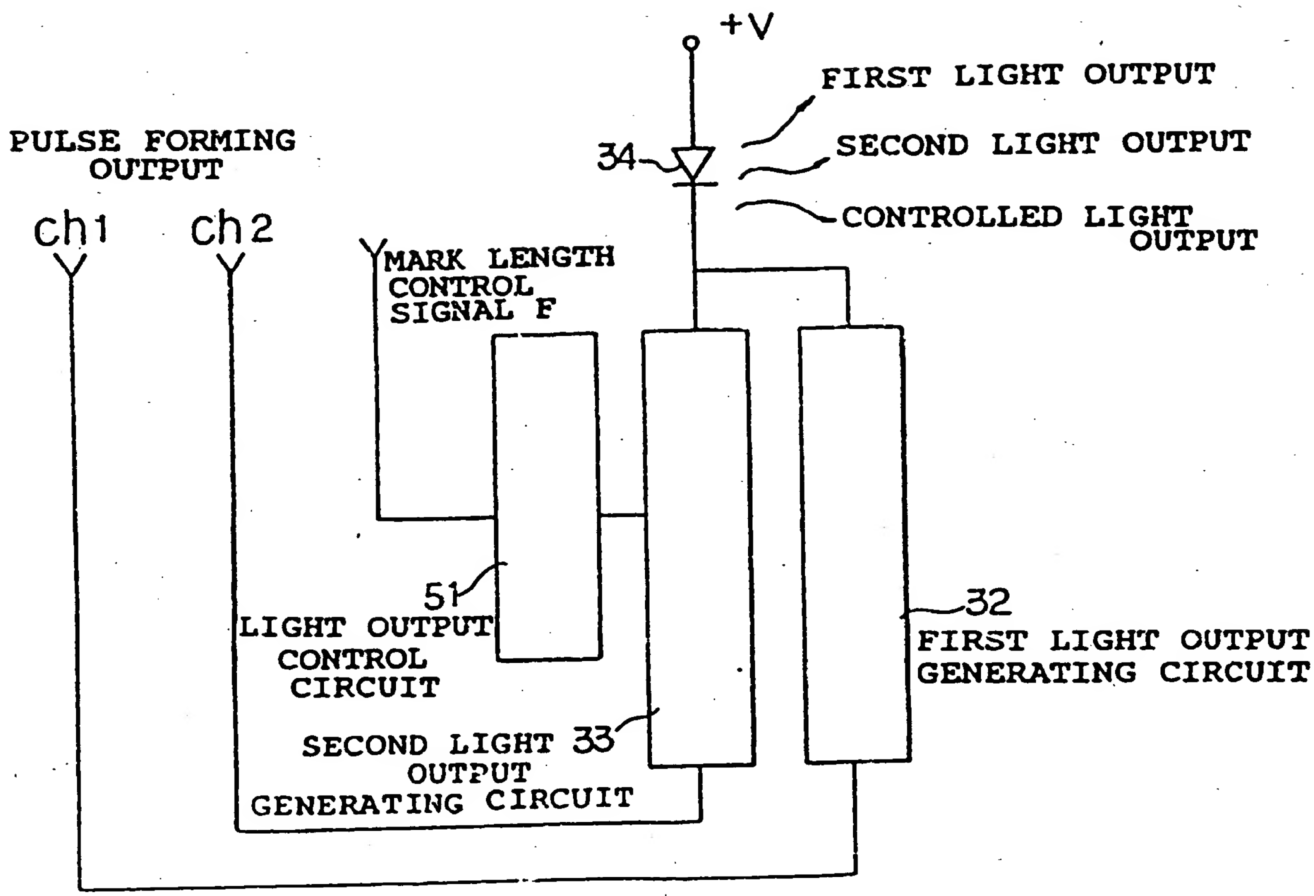

(a)
INPUT CD SIGNAL D0
5τ
START PART CONTROL SIGNAL A
2τ
INTERMEDIATE PART CONTROL SIGNAL B
2τ
END PART CONTROL SIGNAL C
τ
PULSE FORMING CLOCK T = (½) τ
(b)
PULSE PROHIBITION MEANS (X REPRESENTS "PROHIBITION")
START PART ch1 × × O O
ch2 O O × ×
INTERMEDIATE PART ch1 O O O O O O O O O O O O O O O O
ch2 × × × × × × × × × × × × × × × ×
END PART ch1 O ×
ch2 × ×
(c)
PULSE FORMING OUTPUT ch1
PULSE FORMING OUTPUT ch2
(d)
SECOND LIGHT OUTPUT
LIGHT OUTPUT OF LASER DIODE
FIRST LIGHT OUTPUT

FIG. 11



+V
FIRST LIGHT OUTPUT
SECOND LIGHT OUTPUT
CONTROLLED LIGHT OUTPUT
34
PULSE FORMING OUTPUT
ch1
ch2
MARK LENGTH CONTROL SIGNAL F
51
LIGHT OUTPUT CONTROL CIRCUIT
SECOND LIGHT OUTPUT GENERATING CIRCUIT
33
32
FIRST LIGHT OUTPUT GENERATING CIRCUIT

FIG. 12

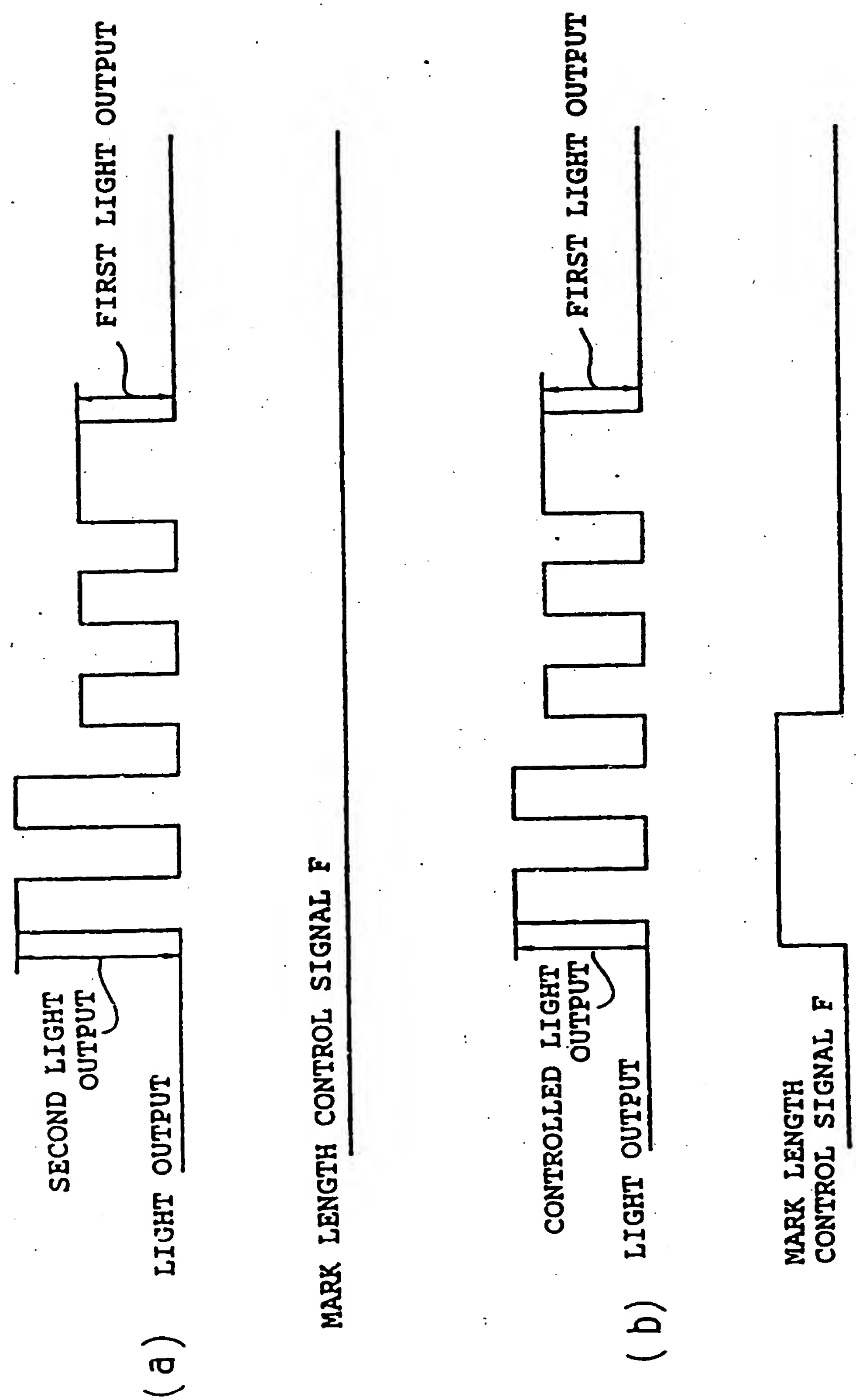
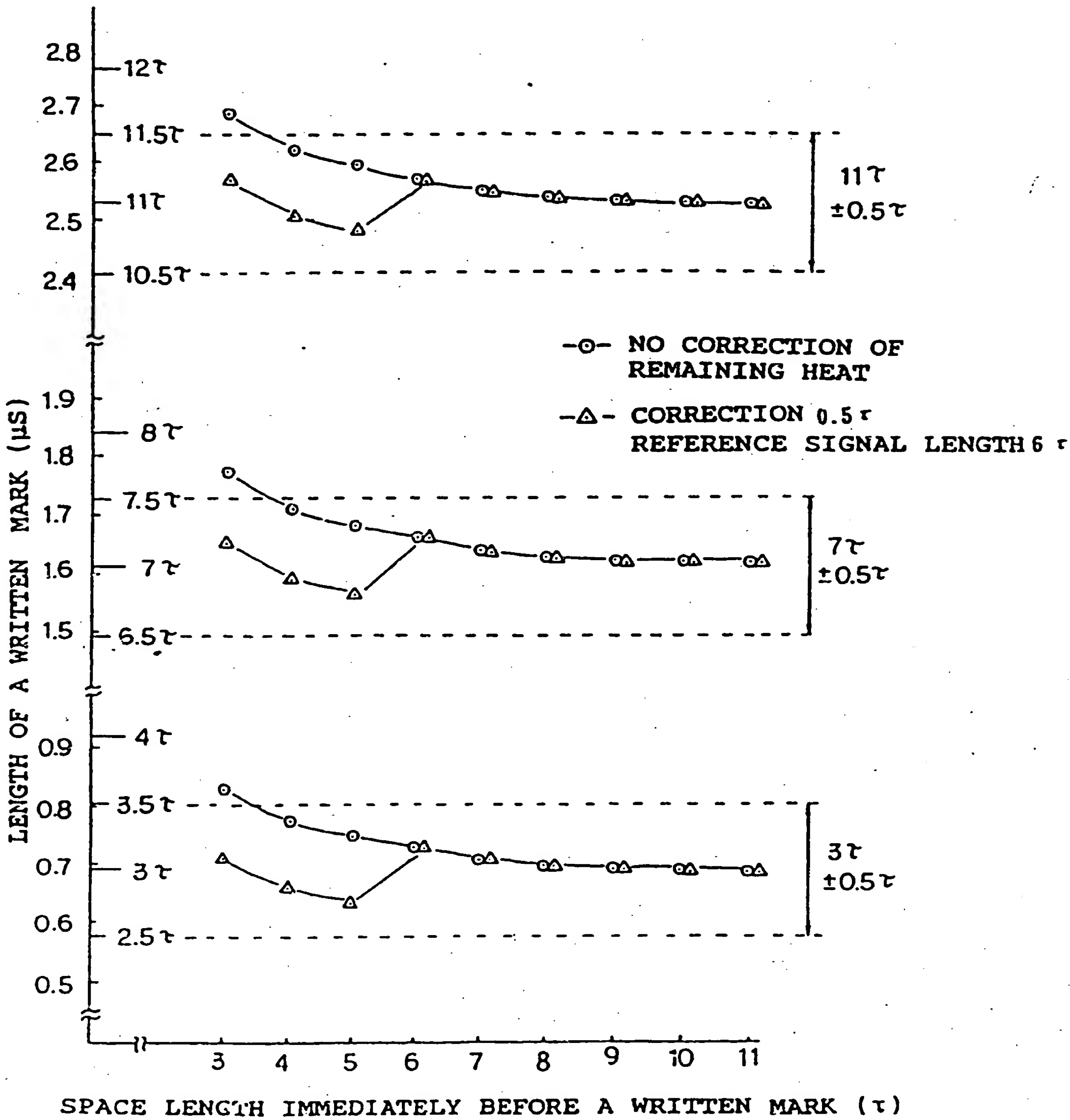

(a)
SECOND LIGHT OUTPUT
FIRST LIGHT OUTPUT
LIGHT OUTPUT
MARK LENGTH CONTROL SIGNAL F
(b)
CONTROLLED LIGHT OUTPUT
FIRST LIGHT OUTPUT
LIGHT OUTPUT
MARK LENGTH CONTROL SIGNAL F

FIG. 13



LENGTH OF A WRITTEN MARK (μS)
2.8
2.7
2.6
2.5
2.4
1.9
1.8
1.7
1.6
1.5
0.9
0.8
0.7
0.6
0.5
12τ
11.5τ
11τ
10.5τ
8τ
7.5τ
7τ
6.5τ
4τ
3.5τ
3τ
2.5τ
11τ ±0.5τ
7τ ±0.5τ
3τ ±0.5τ
NO CORRECTION OF REMAINING HEAT
CORRECTION 0.5τ REFERENCE SIGNAL LENGTH 6τ
3
4
5
6
7
8
9
10
11
SPACE LENGTH IMMEDIATELY BEFORE A WRITTEN MARK (τ)

FIG. 14

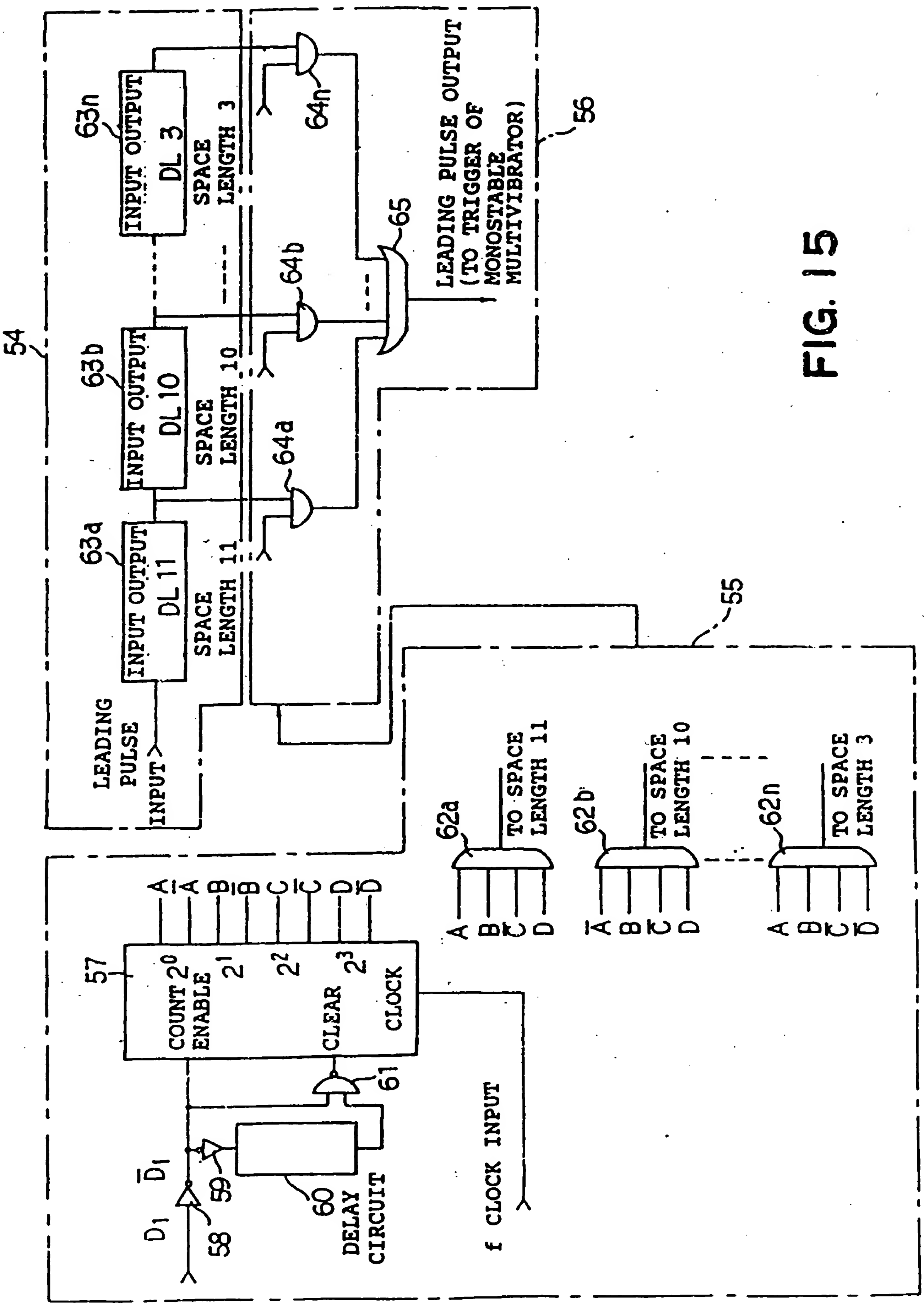

54
63a
INPUT OUTPUT
DL 11
SPACE LENGTH 11
63b
INPUT OUTPUT
DL 10
SPACE LENGTH 10
63n
INPUT OUTPUT
DL 3
SPACE LENGTH 3
64a
64b
64n
65
LEADING PULSE OUTPUT (TO TRIGGER OF MONOSTABLE MULTIVIBRATOR)
56
LEADING PULSE INPUT
55
62a
TO SPACE LENGTH 11
62b
TO SPACE LENGTH 10
62n
TO SPACE LENGTH 3
57
COUNT ENABLE
CLEAR
CLOCK
2^0
2^1
2^2
2^3
A $\bar{A}$ B $\bar{B}$ C $\bar{C}$ D $\bar{D}$
D_1
$\bar{D}_1$
58
59
60
DELAY CIRCUIT
61
f CLOCK INPUT

FIG. 15

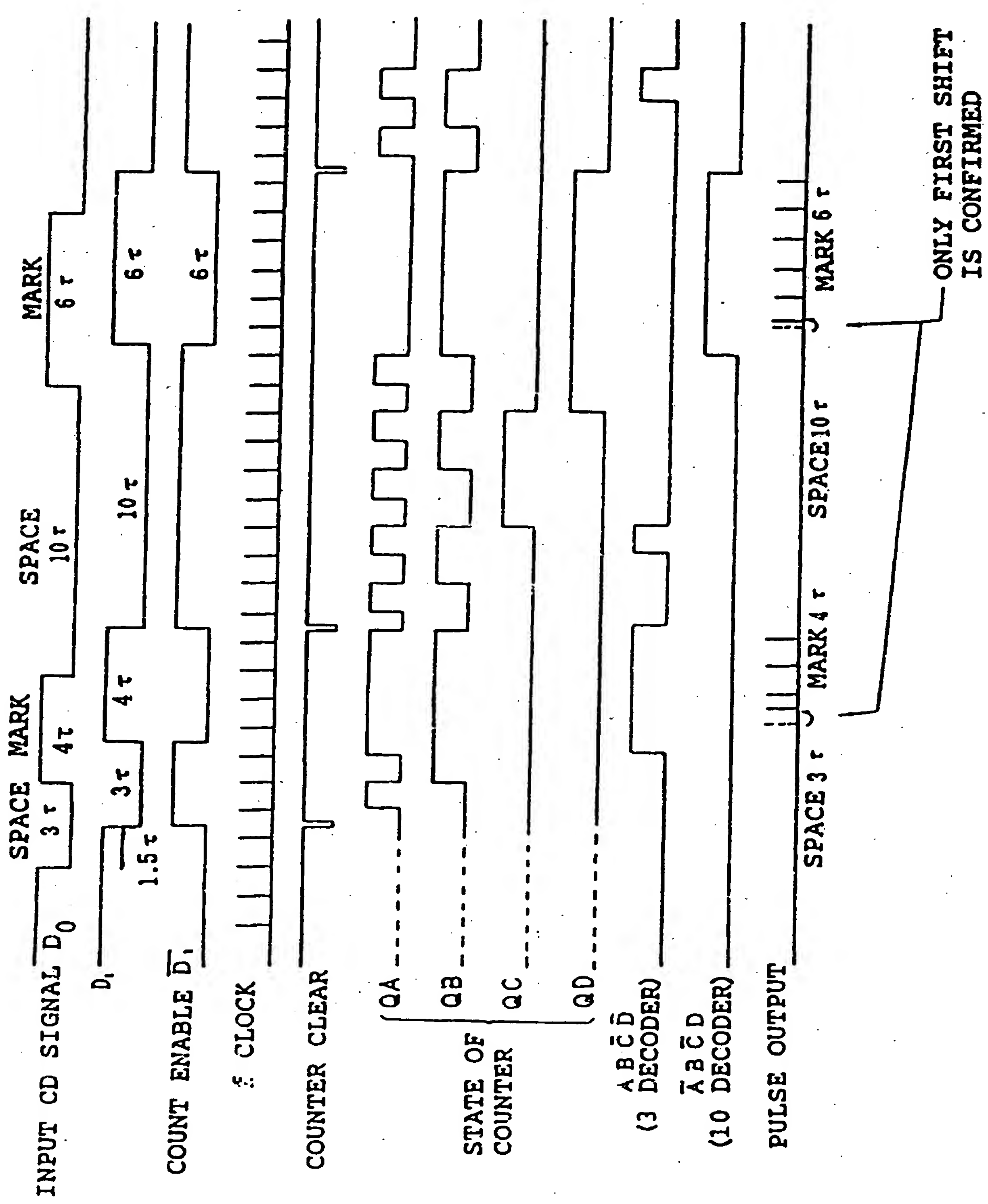

INPUT CD SIGNAL D_0
SPACE 3 τ
MARK 4τ
SPACE 10 τ
MARK 6 τ
D_1
1.5 τ
3 τ
4 τ
10 τ
6 τ
COUNT ENABLE $\overline{D_1}$
4 τ
6 τ
CLOCK
COUNTER CLEAR
STATE OF COUNTER
QA
QB
QC
QD
$AB\bar{C}\bar{D}$ (3 DECODER)
$\bar{A}B\bar{C}D$ (10 DECODER)
PULSE OUTPUT
SPACE 3 τ
MARK 4 τ
SPACE 10 τ
MARK 6 τ
ONLY FIRST SHIFT IS CONFIRMED

FIG. 16

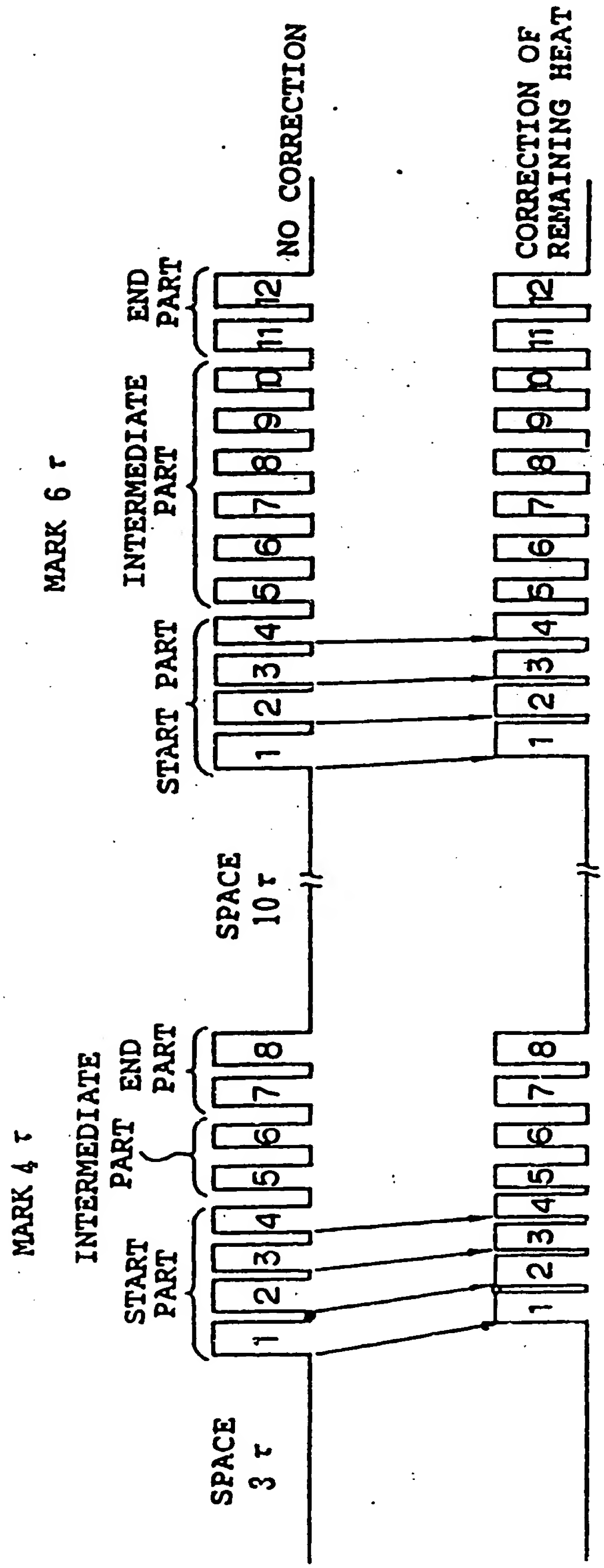

SPACE 3 τ
MARK 4 τ
START PART
INTERMEDIATE PART
END PART
SPACE 10 τ
MARK 6 τ
START PART
INTERMEDIATE PART
END PART
NO CORRECTION
CORRECTION OF REMAINING HEAT

FIG. 17

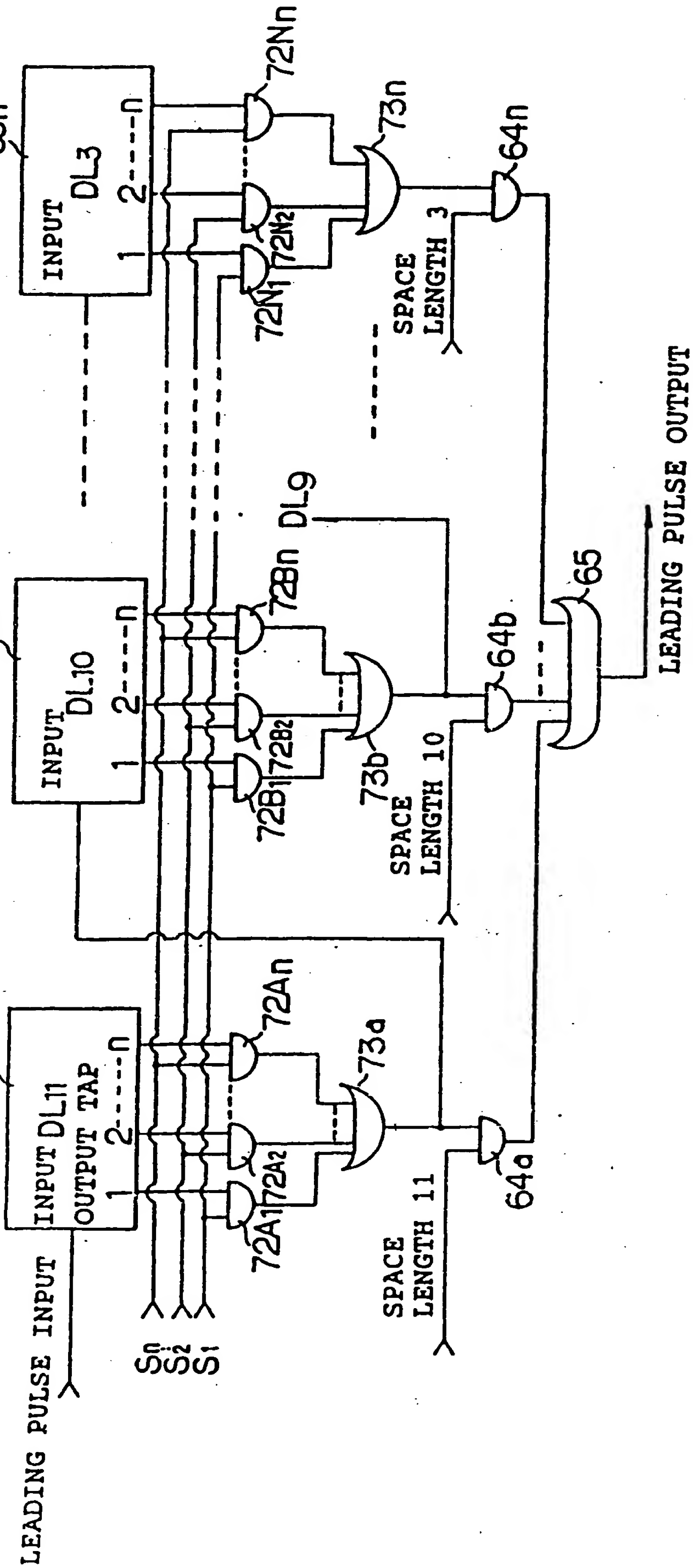

LEADING PULSE INPUT
63a
INPUT DL11
OUTPUT TAP
1
2
n
72A1
72A2
72An
73a
64a
SPACE LENGTH 11
Sn
S2
S1
63b
INPUT
DL10
72B1
72B2
72Bn
73b
64b
SPACE LENGTH 10
DL9
63n
INPUT
DL3
72N1
72N2
72Nn
73n
64n
SPACE LENGTH 3
65
LEADING PULSE OUTPUT

FIG. 18

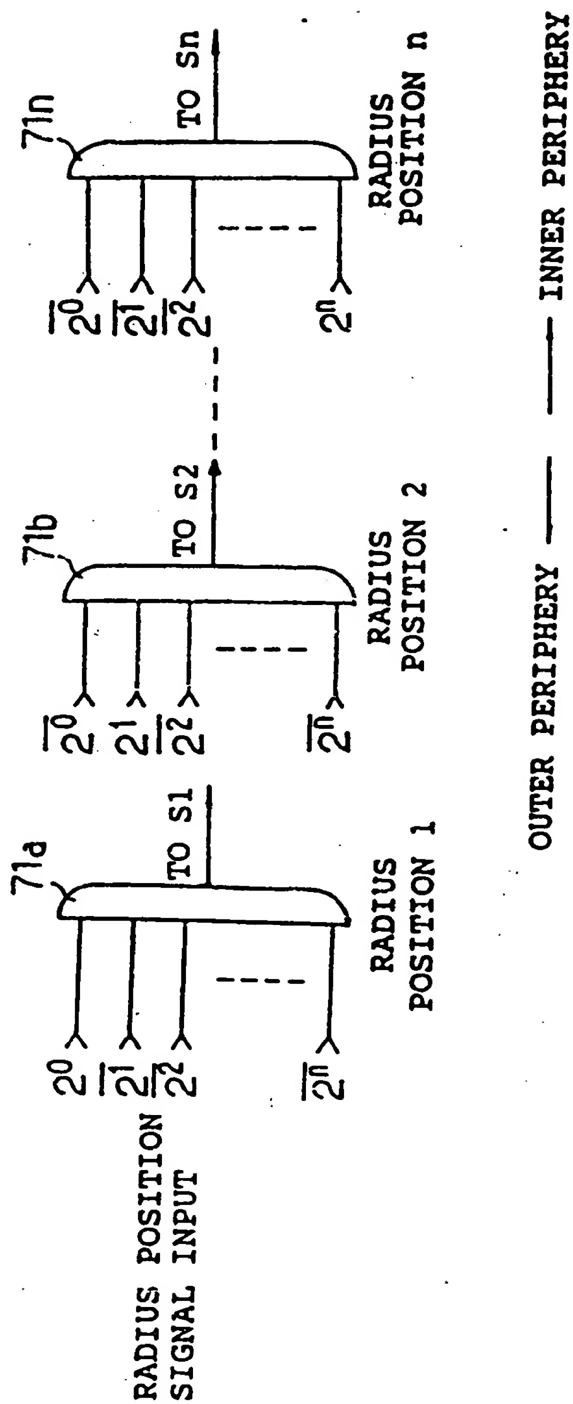

RADIUS POSITION SIGNAL INPUT
71a
TO S1
RADIUS POSITION 1
71b
TO S2
RADIUS POSITION 2
71n
TO Sn
RADIUS POSITION n
OUTER PERIPHERY
INNER PERIPHERY

FIG. 19

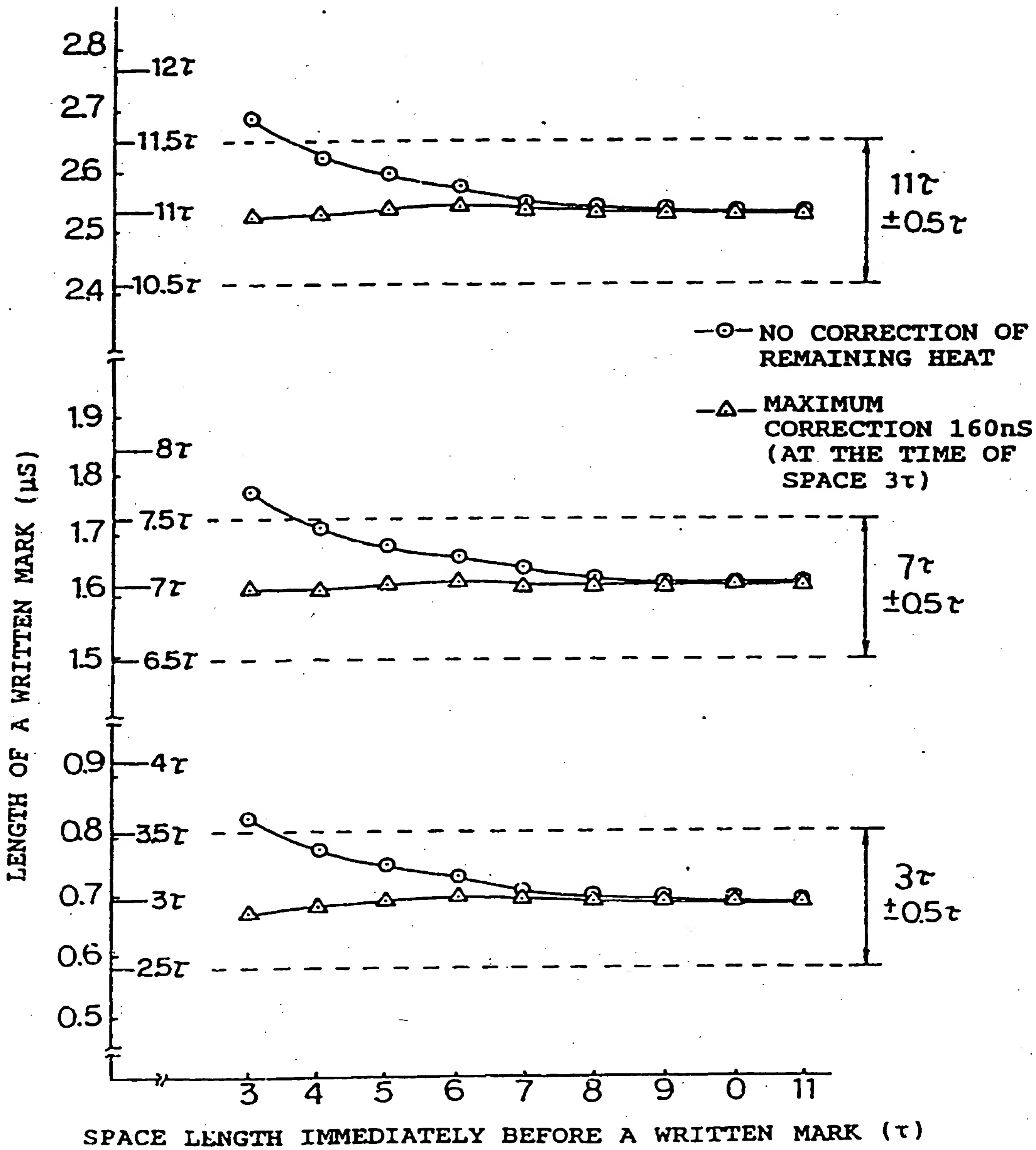

LENGTH OF A WRITTEN MARK (μS)
2.8
2.7
2.6
2.5
2.4
1.9
1.8
1.7
1.6
1.5
0.9
0.8
0.7
0.6
0.5
12τ
11.5τ
11τ
10.5τ
8τ
7.5τ
7τ
6.5τ
4τ
3.5τ
3τ
2.5τ
11τ ±0.5τ
7τ ±0.5τ
3τ ±0.5τ
NO CORRECTION OF REMAINING HEAT
MAXIMUM CORRECTION 160nS (AT THE TIME OF SPACE 3τ)
3
4
5
6
7
8
9
0
11
SPACE LENGTH IMMEDIATELY BEFORE A WRITTEN MARK (τ)

FIG. 20

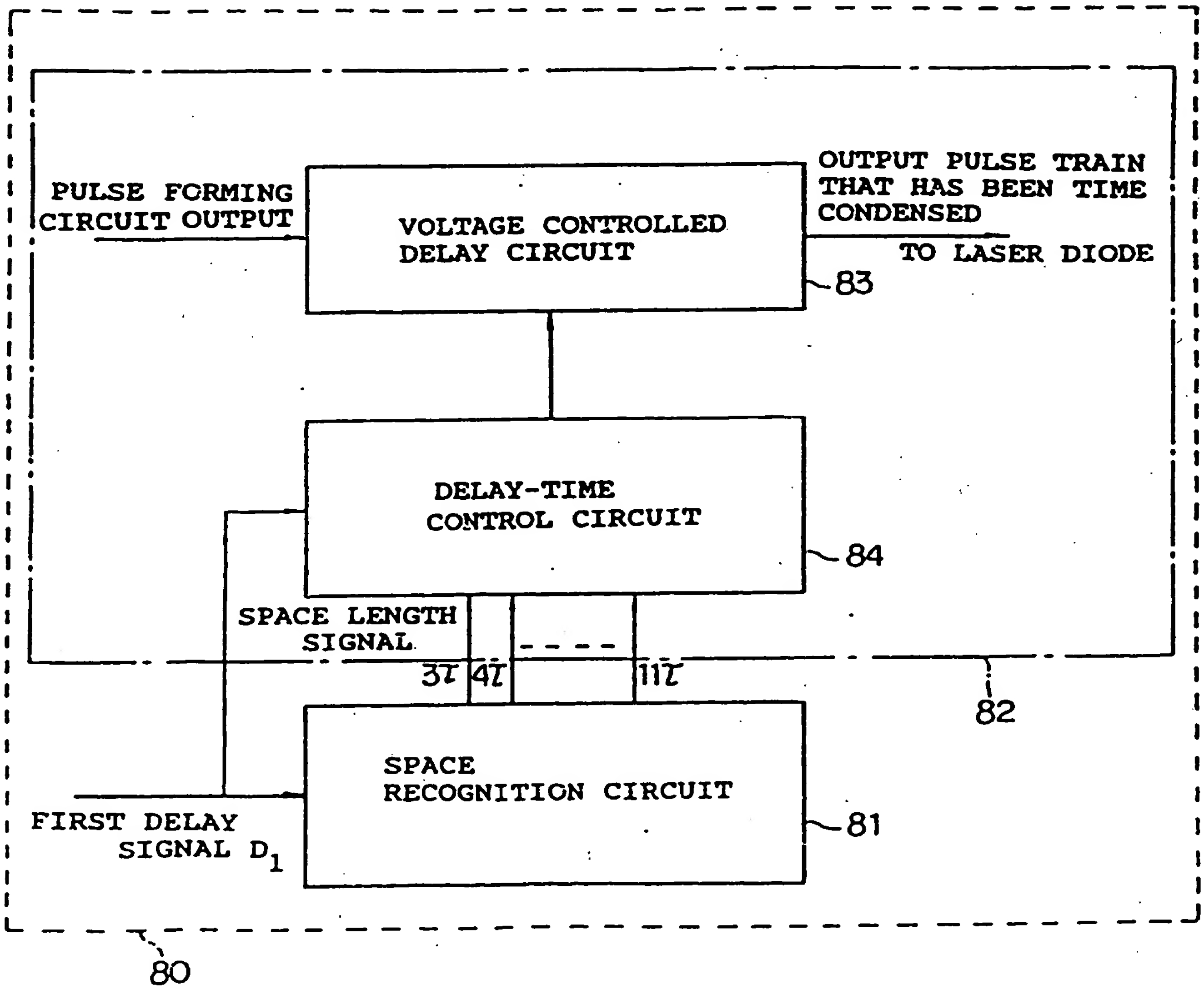

PULSE FORMING CIRCUIT OUTPUT
VOLTAGE CONTROLLED DELAY CIRCUIT
OUTPUT PULSE TRAIN THAT HAS BEEN TIME CONDENSED
TO LASER DIODE
83
DELAY-TIME CONTROL CIRCUIT
84
SPACE LENGTH SIGNAL
3τ
4τ
11τ
82
SPACE RECOGNITION CIRCUIT
FIRST DELAY SIGNAL D1
81
80

FIG. 21

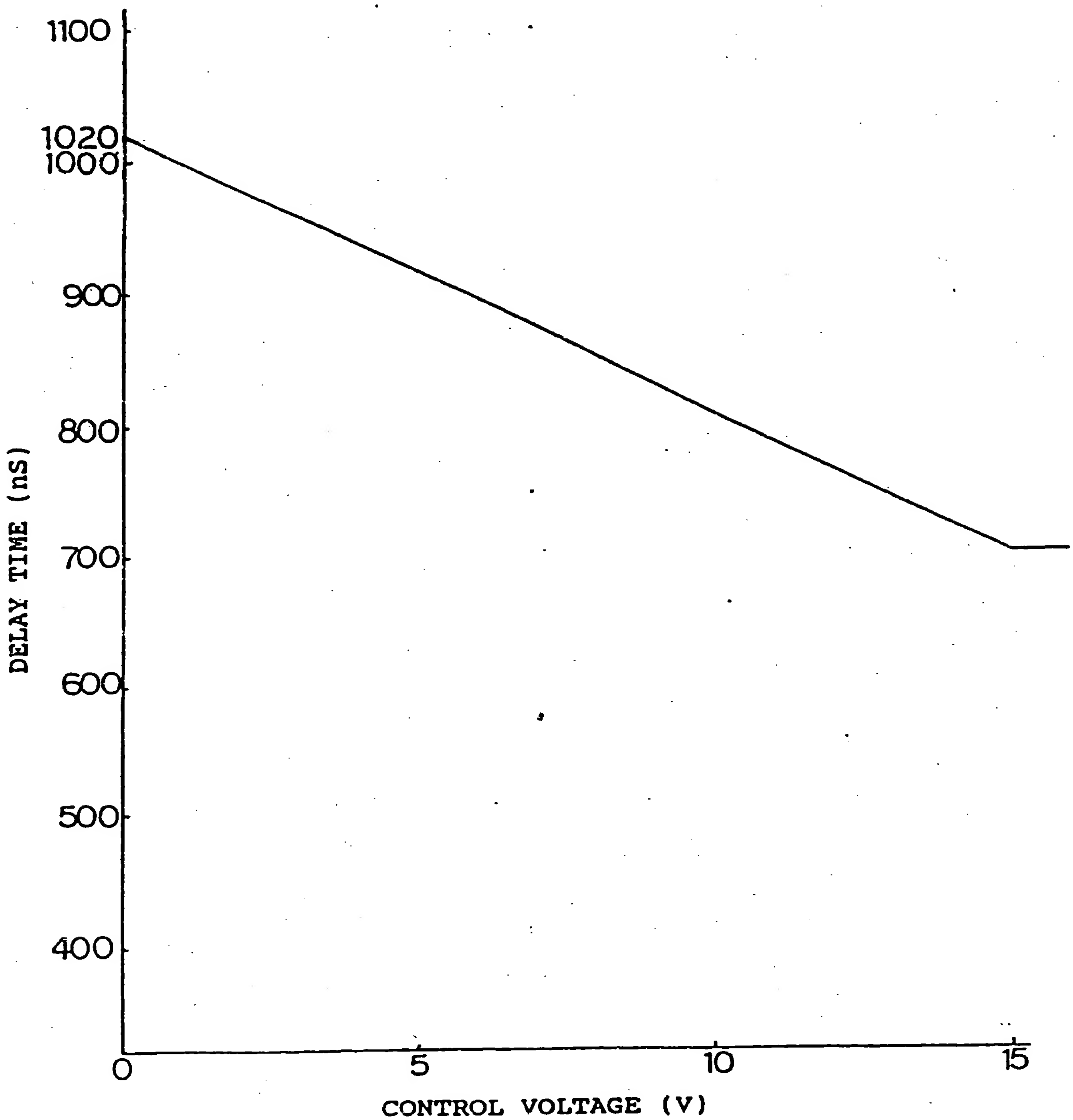

1100
1020
1000
900
800
700
600
500
400
DELAY TIME (nS)
0
5
10
15
CONTROL VOLTAGE (V)

FIG. 22

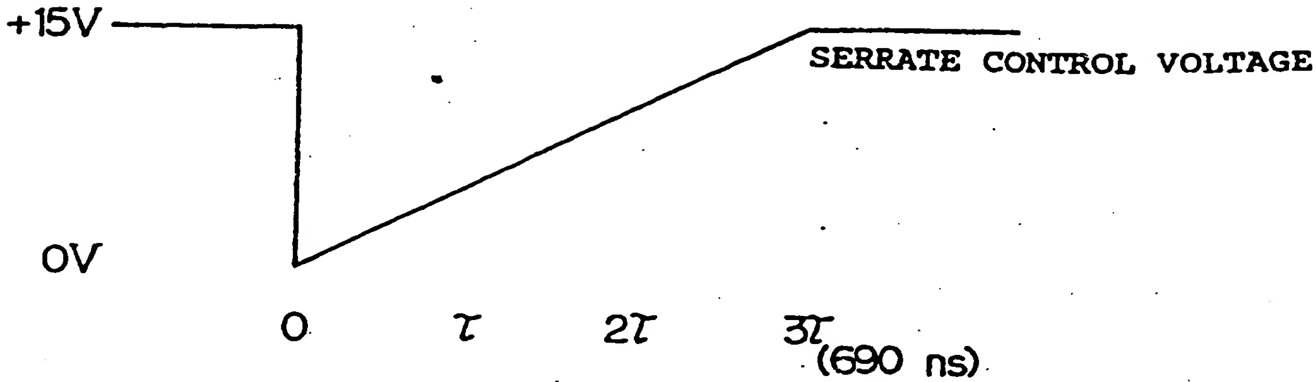


FIG. 23

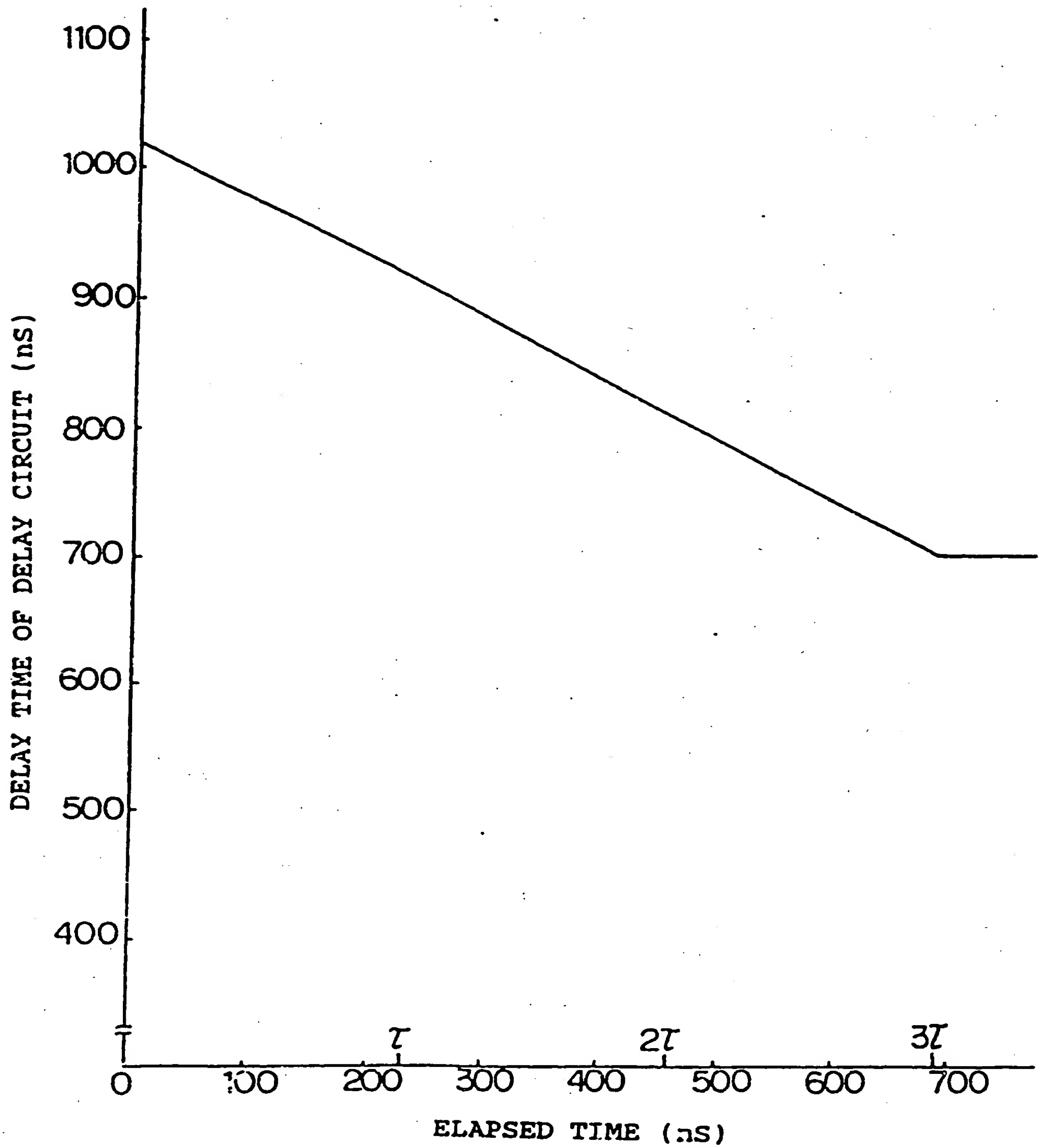

DELAY TIME OF DELAY CIRCUIT (nS)
1100
1000
900
800
700
600
500
400
τ
2τ
3τ
0
100
200
300
400
500
600
700
ELAPSED TIME (nS)

FIG. 24

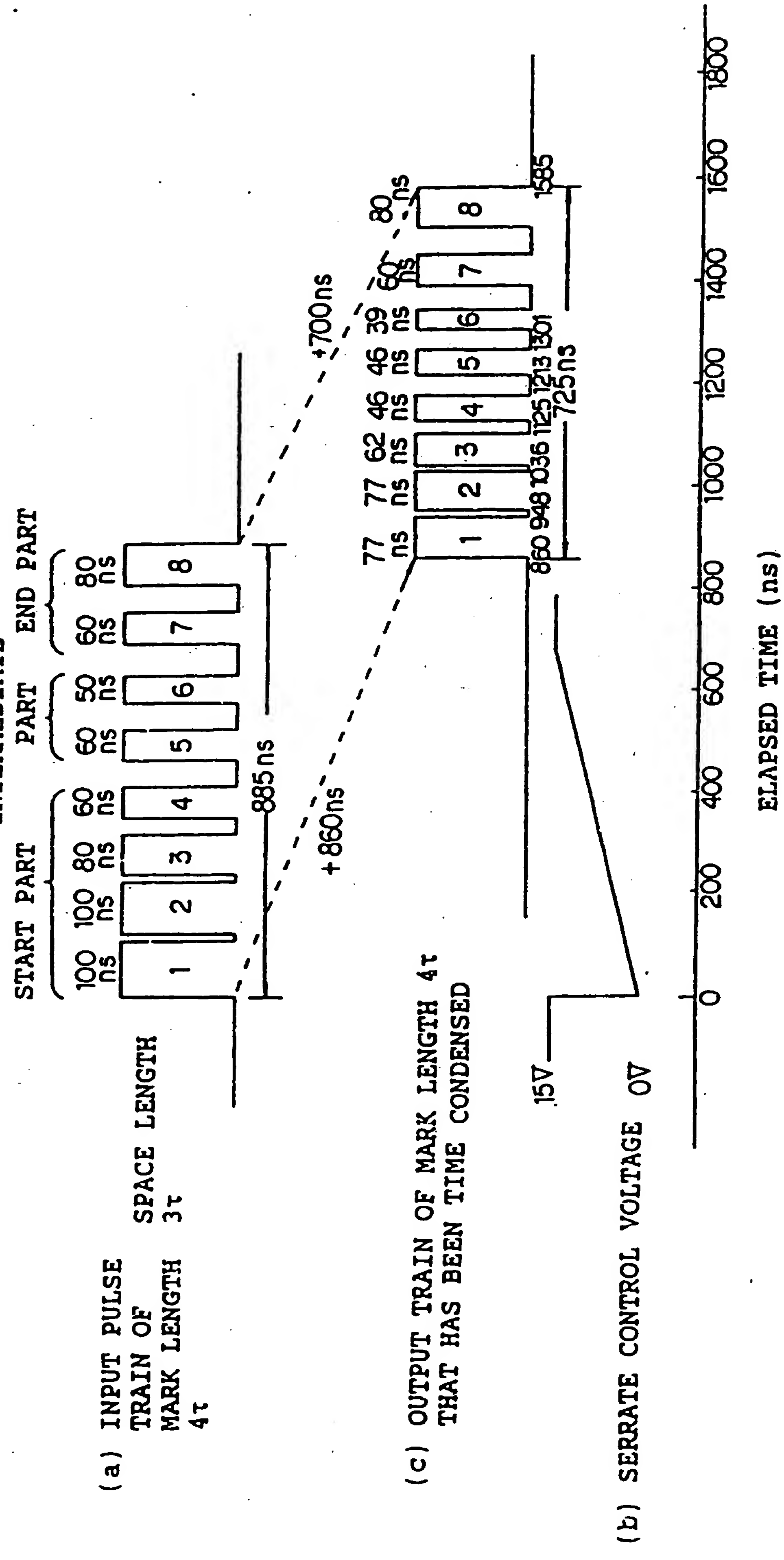
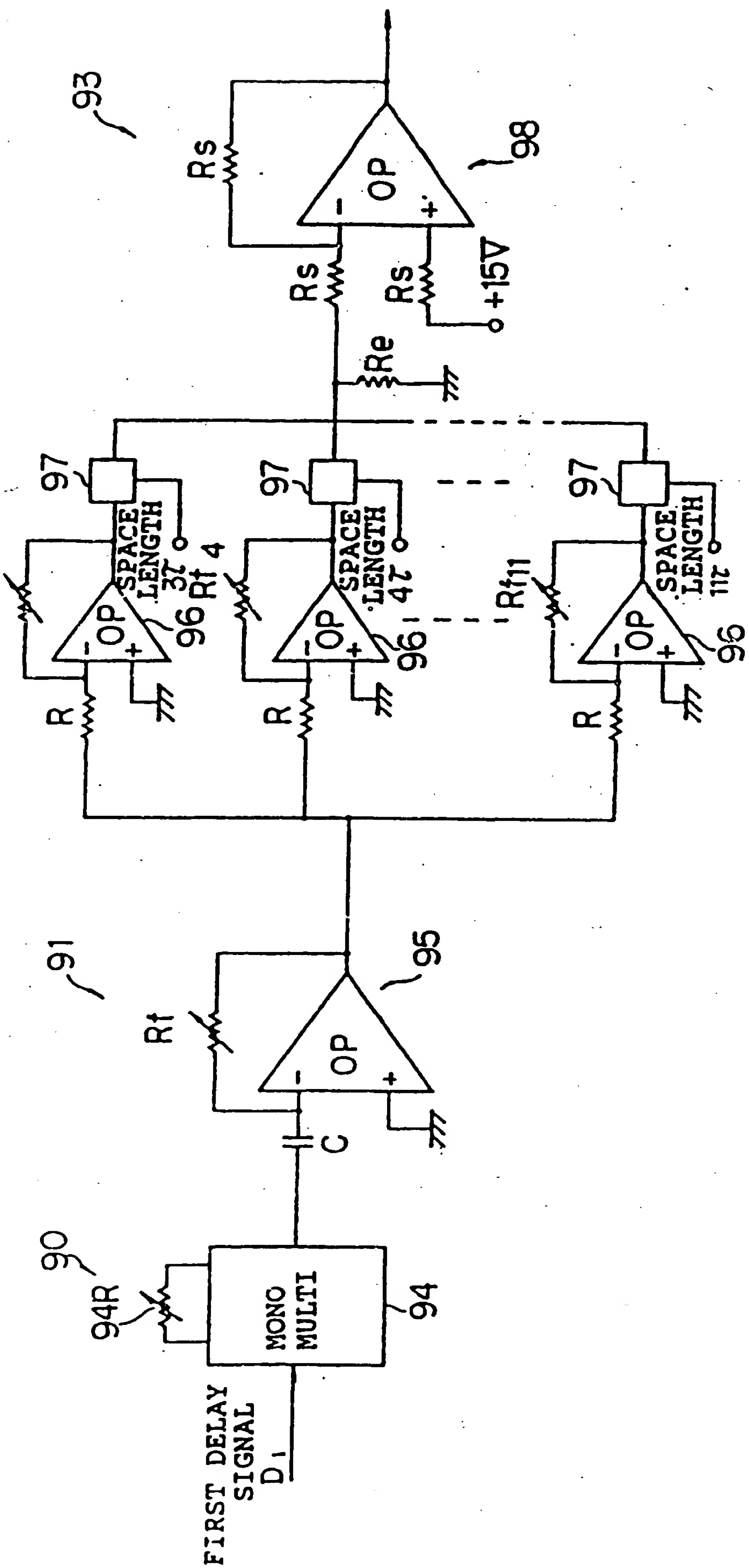

(a) INPUT PULSE TRAIN OF MARK LENGTH 4τ
SPACE LENGTH 3τ
START PART
INTERMEDIATE PART
END PART
100 ns
100 ns
80 ns
60 ns
60 ns
50 ns
60 ns
80 ns
1
2
3
4
5
6
7
8
885ns
+860ns
+700ns
(c) OUTPUT TRAIN OF MARK LENGTH 4τ THAT HAS BEEN TIME CONDENSED
77 ns
77 ns
62 ns
46 ns
46 ns
39 ns
60 ns
80 ns
860
948
1036
1125
1213
1301
1585
725ns
(b) SERRATE CONTROL VOLTAGE
15V
0V
0
200
400
600
800
1000
1200
1400
1600
1800
ELAPSED TIME (ns)

FIG. 25



FIRST DELAY SIGNAL D1
MONO MULTI
94R
94
90
C
OP
Rf
95
91
R
OP
Rf3
Rf 4
Rf11
SPACE LENGTH 3T
SPACE LENGTH 4T
SPACE LENGTH 11T
96
97
92
Re
Rs
Rs
Rs
+15V
OP
98
93

FIG. 26

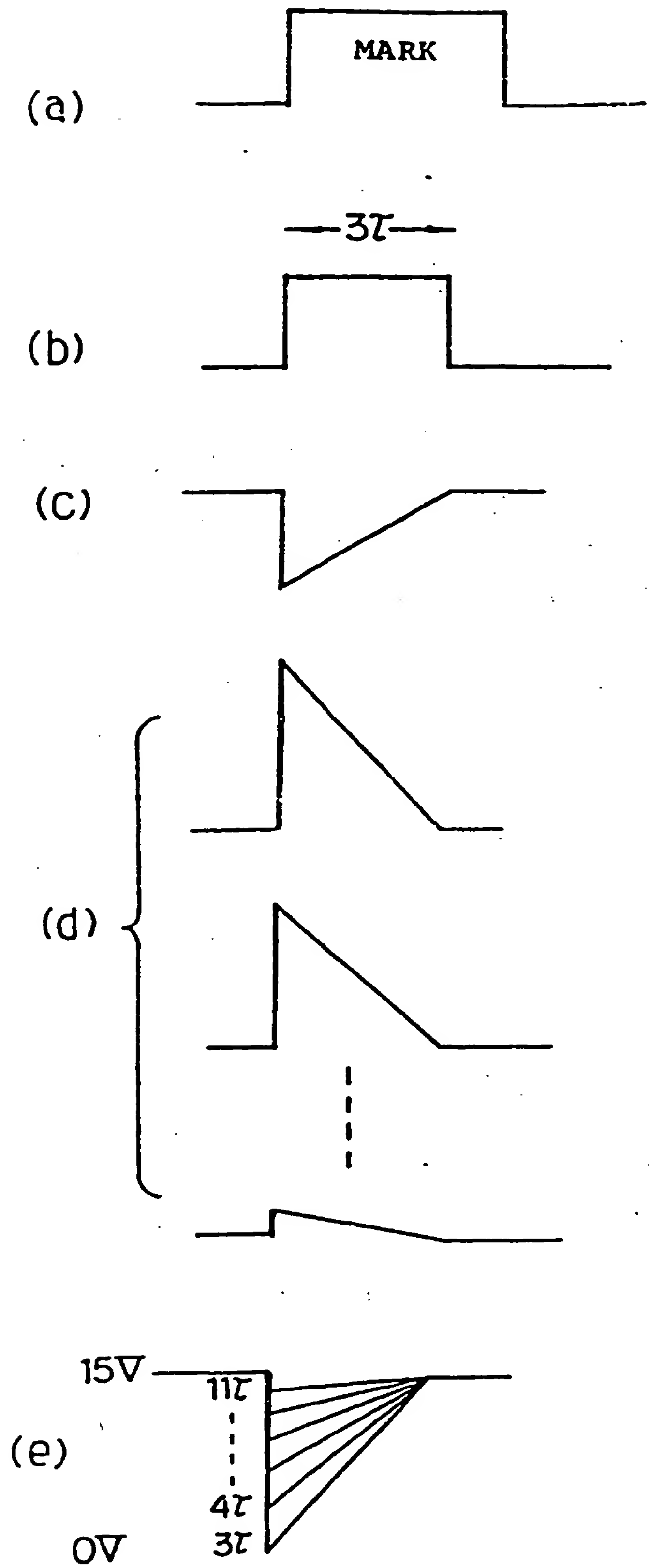


FIG. 27

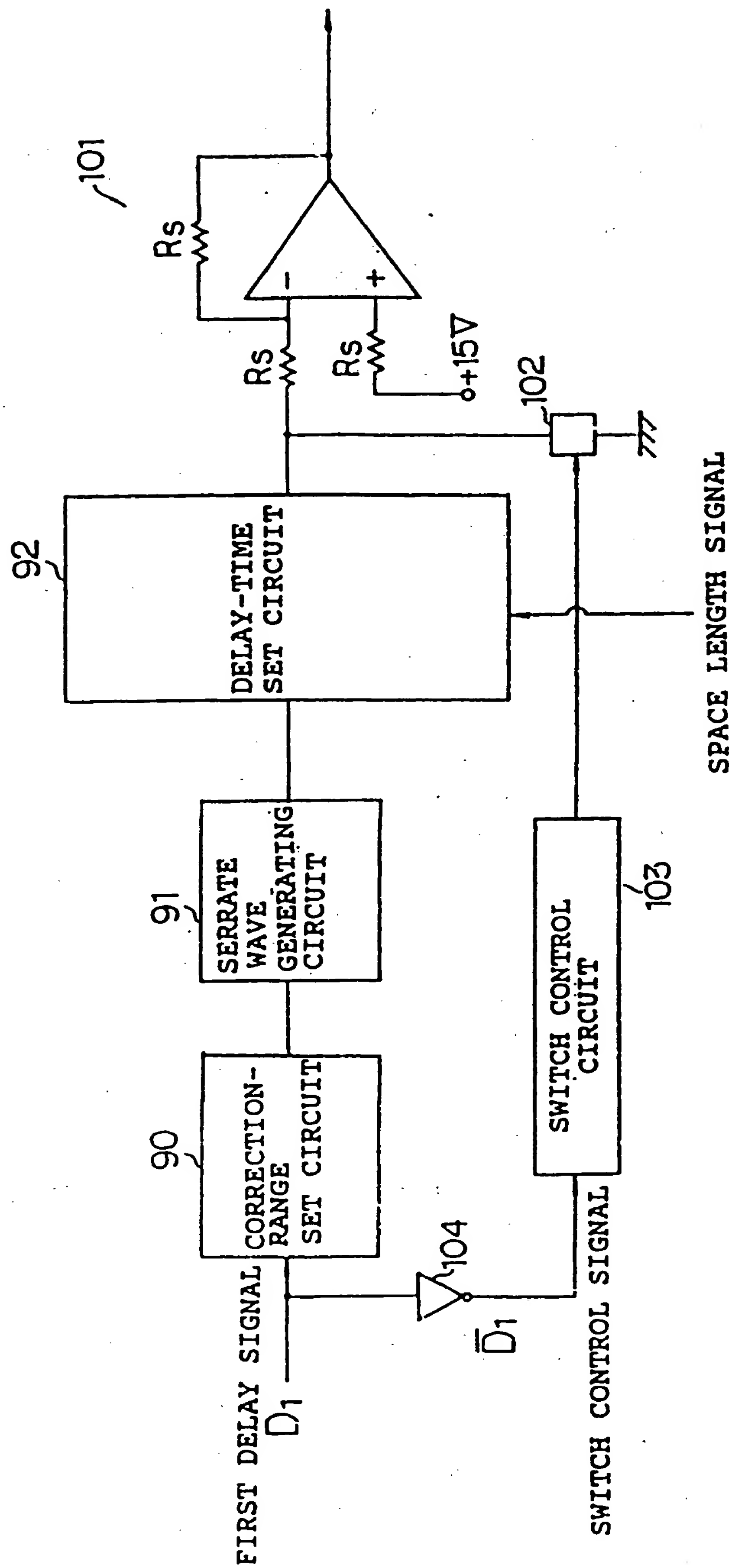

101
Rs
Rs
Rs
+15V
102
92
DELAY-TIME SET CIRCUIT
SPACE LENGTH SIGNAL
91
SERRATE WAVE GENERATING CIRCUIT
103
SWITCH CONTROL CIRCUIT
90
CORRECTION-RANGE SET CIRCUIT
104
FIRST DELAY SIGNAL D_1
$\overline{D_1}$
SWITCH CONTROL SIGNAL

FIG.28

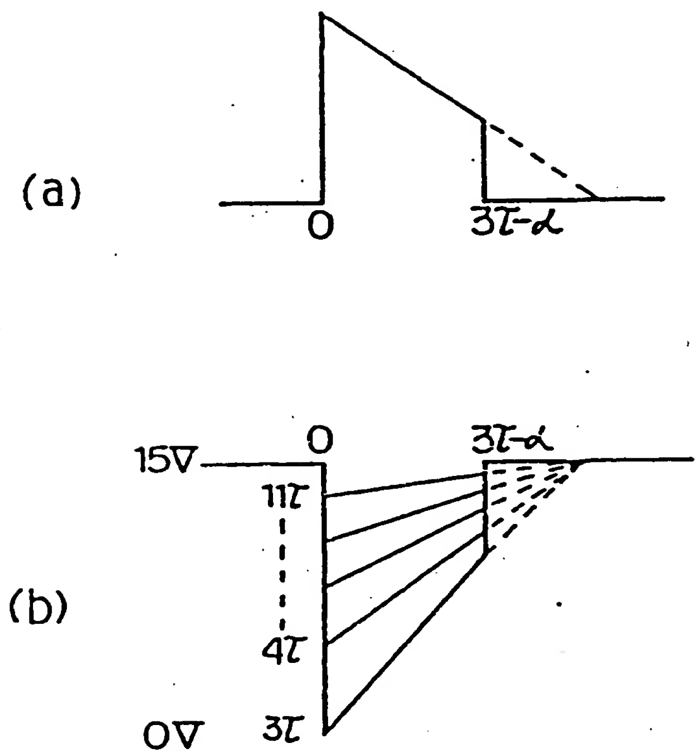


FIG. 29

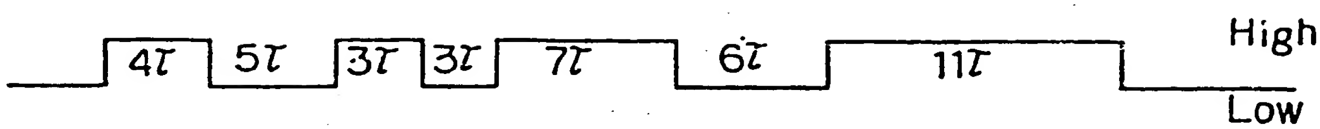
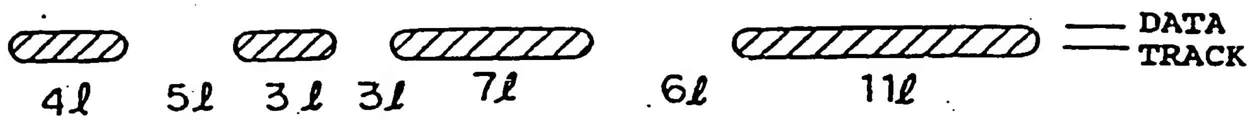
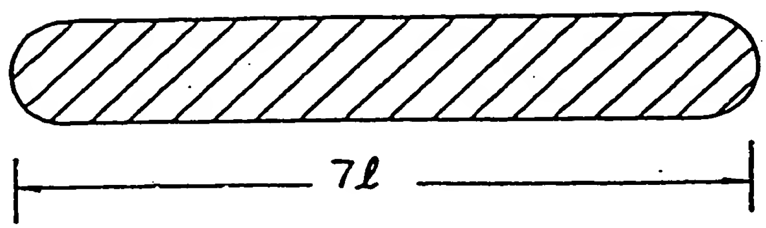


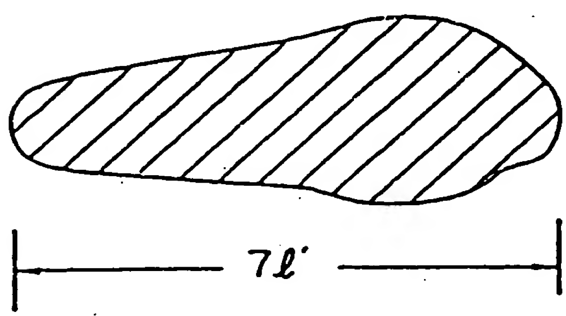
FIG. 30



(a) PITS WRITTEN ON MEDIUM



(b) NORMAL SHAPE OF A WRITTEN PIT



(c) ABNORMAL SHAPE OF A WRITTEN PIT

FIG. 31

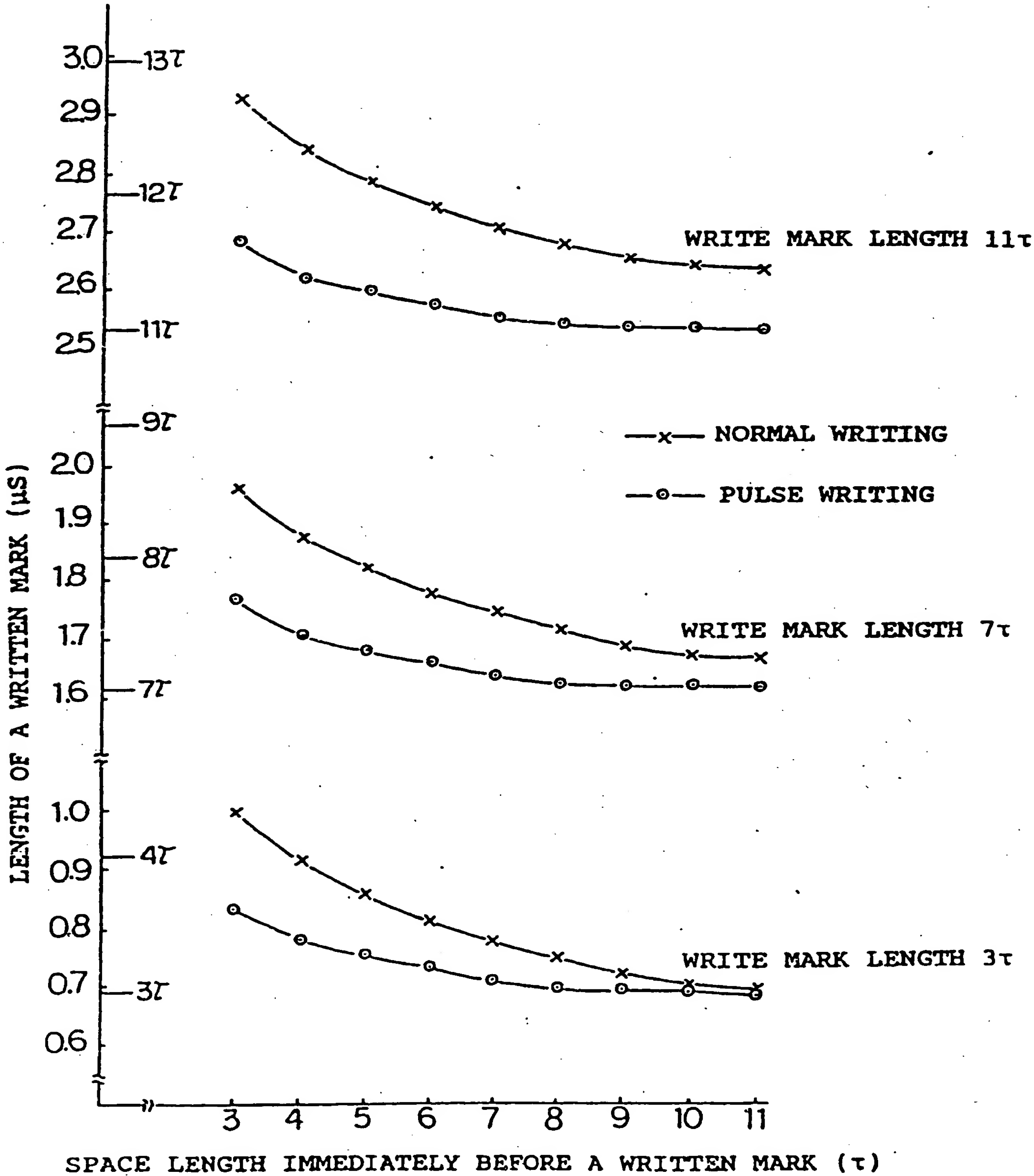

3.0
2.9
2.8
2.7
2.6
2.5
2.0
1.9
1.8
1.7
1.6
1.0
0.9
0.8
0.7
0.6
13τ
12τ
11τ
9τ
8τ
7τ
4τ
3τ
WRITE MARK LENGTH 11τ
WRITE MARK LENGTH 7τ
WRITE MARK LENGTH 3τ
NORMAL WRITING
PULSE WRITING
LENGTH OF A WRITTEN MARK (μS)
3
4
5
6
7
8
9
10
11
SPACE LENGTH IMMEDIATELY BEFORE A WRITTEN MARK (τ)

FIG. 32